Synthetic Theater of War - Europe (STOW-E) Final Report

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ADMINISTRATIVE INFORMATION

This report details a joint research effort, the Synthetic Theater of War - Europe (STOW-E), that was run concurrently with ATLANTIC RESOLVE 94, a joint service training exercise. The report was developed by the Naval Command, Control and Ocean Surveillance Center, RDT&E Division, San Diego, CA 92152–5001, with support from other contractor agencies.

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EXECUTIVE SUMMARY

Seven technologies and six techniques were developed and/or integrated for the Synthetic Theater of War - Europe (STOW-E) as a stepping stone on the path to STOW97. Each technology and technique is summarized below and illustrated in table I with an evaluation of its necessity and its adequacy for STOW97.

Table I. Technologies and techniques evaluation.

	STOW-E	STOW-E	STOW97	STOW97
	Necessary	Adequate	Necessary	Adequate
Technologies				
Aggregation/Deaggregation	Yes	Yes	TBD	No
Defense Simulation Internet	Yes	Yes	Yes	No
Scaleability	Yes	Yes	Yes	No
Live/Range Instruments	Yes	Yes	Yes	No
Terrain Database	Yes	Yes	Yes	No
ModSAF	No	Yes	Yes	No
IFOR	No	Yes	Yes	No
Techniques				
Experimental PDUs	Yes	Yes	Yes	No
Security	Yes	Yes	Yes	No
Tactical Communications	Yes	Yes	Yes	No
Technical Control	Yes	Yes	Yes	No
Data Collection and Analysis	Yes	Yes	Yes	No
Test and Integration	Yes	Yes	Yes	No

TECHNOLOGIES

Aggregation/Deaggregation

This technology was necessary for STOW-E to link a constructive model, such as the Battalion/Brigade Battle Simulation (BBS), that uses icons representing multiple individual entities, with a virtual model, such as Simulation Network (SIMNET) or Distributed Interactive Simulation (DIS) technologies, where all units are represented as individual entities.

To bridge the gap between the constructive simulation and the virtual simulators, an aggregation/deaggregation technology was created by integrating the Advanced Interface Unit (AIU) and the Semi-Automated Forces (SAF) engine. The AIU provided the interfaces between the BBS simulation and the SIMNET simulators, performed translation between DIS and SIMNET protocols, performed dead reckoning of DIS entities, and provided necessary functionality that was missing in the SAF. The SAF engine performed the actual modeling of the deaggregated BBS entities as individual vehicles, and provided several basic maneuver and combat support functions.

The goal of the aggregation/deaggregation project for STOW-E was to implement the BBS/SIMNET interface into an operational exercise and include interactivity with the Combat Maneuver Training Center (CMTC) Live Instrumented Range, thus providing the enabling technologies for aggregate-level constructive wargaming systems (BBS), individual virtual simulators (SIMNET), and individual live combatants (CMTC - Instrumentation System [CMTC-IS]) to interact in a joint training exercise.

Achievements during STOW-E include many successful interactions between the constructive, virtual, and live domains. BBS tank platoons engaged and destroyed SIMNET tank simulators, and fired on CMTC-IS real tanks. BBS artillery missions were successfully fired and BBS minefields were emplaced. Both were effective against SIMNET tank simulators. SIMNET tank simulators were able to pull up next to BBS fuel tankers and cargo trucks, and receive the appropriate fuel and ammunition resupply. BBS aircraft (fixed and rotary wing) engaged and destroyed SIMNET tank simulators. BBS air defense vehicles engaged and destroyed Ft. Rucker helicopter simulators and the Grafenwoehr Falcon Star (F-16) simulator. SIMNET tank simulators and Ft. Rucker helicopter simulators saw BBS aggregate units as individual vehicles, and engaged and destroyed BBS individual vehicles. The Falcon Star simulator engaged and destroyed BBS vehicles, and CMTC-IS fired artillery and destroyed BBS vehicles.

There were several problems detected during STOW-E. The BBS/AIU hash table filled up after 2048 entity entries causing the process to stop. There were problems with SAF movements involving travel—on road, water hazards, and tree canopies, and occasionally aircraft would wander off course. SAF minefield markers looked different on different Stealths, and the orientation of breach markers was wrong. There were problems with the SAF terrain database where entities hit steep, vertical walls and got stuck, and then started flipping around. There was no control over target acquisition; therefore, as soon as line of sight was established, the SAF vehicles acquired the SIMNET vehicles and immediately fired. The capability of more SAF entities is needed. (Right now, moving to ModSAF, goes toward less SAF entities.) The current naming conventions for CMTC-IS and BBS are different. This caused problems with BODAS. The memory on the AIU Central Processing Unit card was near capacity during STOW-E.

As the capability of the system continues to be pressed and expanded, there may need to be a re-evaluation to determine if the current design can reach the next plateau. While the capabilities were rapidly increased from FireStarter to STOW-E, the system may be reaching certain limitations. During STOW-E, the SAF engine was the limiting factor in entity count capacity. Entity counts fluctuated from 1163 to 1637 entities, depending on the training mission.

If there are no aggregate-level constructive wargaming systems participating at STOW97, then this aggregation/deaggregation technology would not be necessary. If there are, then the adequacy of this technology would have to be re-evaluated due to the high entity counts required for STOW97.

Defense Simulation Internet

The Defense Simulation Internet (DSI) is an Internet Protocol based network that provides real-time simulation and video teleconferencing to approximately 100 subscribers worldwide. The DSI utilizes the Stream Protocol to accommodate real-time applications and to support bandwidth reservation and multicast capability. The DSI was necessary in supporting the communications requirements for STOW-E, which incorporated 13 DSI sites in the Continental United States (CONUS), Germany, and England. The classification of the exercise was a combination of Secret No-Foreign and US1.

To support a seamless battle simulation for STOW-E, DSI required a large bandwidth and robust topology. Various network components were upgraded to increase available bandwidth. In addition, augmenting systems, such as the application gateway, were developed to optimize bandwidth utilization.

For the execution of STOW-E over the period of 4 to 7 November '94, during operations that were approximately 16 hours per day, reliability of the DSI was 99% due to network changes (improved switches and redundancy in circuit routing to the sites). Reliability was measured in terms of hours scheduled versus hours usable by simulations to conduct testing. Two notes need to supplement this apparent superb network performance. First, the network was manned 24 hours a day at every site by both the DSI "manufacturer" and by the DSI "operations and maintenance" contractor. Secondly, the network was brought down every night for maintenance and re-boot and systematically brought back up. This process took 2 hours nightly. While the success of the DSI was overwhelmingly positive and a key factor in the overall success of STOW-E, it was not a hands-off operation. Extraordinary effort and hands-on care was devoted to the network throughout the STOW-E period.

Over 99% of the traffic on DSI during STOW-E was DIS Protocol Data Units (PDUs). The average total scenario load between 4 to 7 November STOW-E operations was approximately 900 to 1300 entities depending on the operation for that day. The peak each day during STOW-E was normally around 1800 fully interactive entities. Scenario load during testing prior to STOW-E did reach 3500 entities on one occasion. The DSI was reliable during all of these circumstances.

The DSI, in its current configuration, would not be adequate for STOW97 since the load required for STOW97 would exceed the current available DSI bandwidth.

Scaleability

The goal of the Scaleability program is to support the evolution of DIS technology by pushing back the limitations on the number of entities that can participate in an exercise. This is a necessary technology since the load on the simulation network grows in proportion to the entity count. The load, at some point, will exceed the available bandwidth. To push back this boundary, techniques were developed to increase the density of information that can be transmitted across a given bandwidth.

For STOW-E, approximately 1800 entities were generated at sites around the world. Because of the geometry of the sites on the network, high-traffic segments of the DSI needed to support a traffic load of 4.9 megabits per second (Mbps). The DSI was limited to a throughput of 1.1 Mbps, however, so the offered load to the network had to be reduced by approximately 80%.

To accomplish the required reduction in bandwidth demand, a means was developed to transparently determine whether generated data is of value to other sites in the exercise. If the data is required by another site, it is passed on to the Wide Area Network (WAN); if not, the WAN will never see this additional and unnecessary load. This decision-making function was housed in a computer on each Local Area Network (LAN) referred to as an Application Gateway (AG). The AG further reduced the offered load to the WAN by reformatting the data to achieve more efficient transmissions.

AG performance was successful during STOW-E. AG availability was 99.6%, and the offered load to the network, as measured in pps, was reduced by a 15:1 ratio.

While the AG provided the means to scale the Long Haul Network bandwidth to operate within its capacity, it did not solve management of the LANs. Significant attention must be given to LAN and legacy system capacities for future STOW demonstrations/exercises.

Scaleability technology will be necessary for STOW97 to some degree, depending on the DSI network configuration and the required network load versus available bandwidth.

Live/Range Instrumentation

This technology was necessary for STOW-E to integrate live forces from instrumented ranges via DIS. Live systems encounter different challenges than virtual and constructive systems. Some of the challenges particular to live systems include occasional position inaccuracy and loss of connectivity, limited bandwidth between the range and central instrumentation system, data latency, exercise control limitations, differences in exercise topology between live, constructive, and virtual systems, environmental effects, and data completeness. In order to provide the live element of STOW-E, the CMTC-IS, the Tactical Aircrew Combat Training System (TACTS), and USS *Hue City* were integrated to the DIS network.

These technologies will be necessary for STOW97 if live forces are to be integrated with virtual and constructive forces. The adequacy of these technologies for STOW97 will depend on which simulation systems are used.

Combat Maneuver Training Center (CMTC)

The CMTC-IS, located in Hohenfels, Germany, was designed and developed to support, through analysis and feedback, U.S. Army, Europe, combined arms training. The instrumented CMTC monitors and controls maneuver training, produces after-action reviews (AARs), standardizes evaluation of training performance, and provides detailed training feedback.

In order for CMTC-IS to participate in STOW-E, an interface was designed and developed to provide a gateway to the DIS network and thus a link to other simulations. The CMTC-IS Brigade Operations Display and AAR System (BODAS) provided the CMTC-IS to DIS interface, the DIS to brigade operations interface, the brigade-level display capability, and the brigade-level AAR.

During STOW-E, DIS PDUs representing live units in the Hohenfels Training Area, were successfully transmitted to the DIS network for interaction and display with other systems in Germany. This technology, along with BODAS and the integration of other DIS systems, allowed the brigade commander at CMTC-IS to experience a seamless brigade-level battle. Some problems were detected in the CMTC-IS to DIS interface, DIS to BODAS interface, and brigade exercise control, monitoring, and AAR areas.

Tactical Aircrew Combat Training System (TACTS)

The Tactical Aircrew Combat Training System (TACTS) ranges are advanced training systems designed to provide an effective means to improve air crew proficiency in Air-Air, Air-Surface Combat, and Electronic Warfare mission areas.

The primary goal in STOW-E was to provide an interface unit to allow aircraft positional data and weapon release signals provided by the TACTS range to be transformed to the DIS protocol to provide interaction with other virtual simulation systems. Connectivity of live aircraft with the DSI was accomplished via the Tactical Aircrew Combat Training System/Air Combat Maneuvering Instrumentation (TACTS/ACMI) air/ground radio frequency data link. The TACTS/ACMI integration effort required the development of the Advanced Interface Units–ground (AIU_gs) to provide the interfacing function between the DSI and the TACTS range. The AIU_gs is the gateway between the TACTS/ACMI system and the ground-based simulation network.

Accomplishments include the AIUgs' ability to produce a detonation PDU when the accumulated "probability of kill" reached a specified level. A live F/A-18 (Cherry Point) was able to be controlled by an E-2C controller (Patuxent River), via the V4 communications network. The controller was able to see the F/A-18 on his tactical displays and vector the pilot in for a laser-guided bomb drop against a hostile target.

USS *Hue City*

The stated primary objective of the Navy during STOW-E was to demonstrate the potential to train personnel at all levels (from individual tactical console operators up through the Battle Group Commander) in a DIS environment. Additional goals included exposing the Fleet to DIS simulation potential, accelerating development of the Battle Force Tactical Trainer (BFTT), and bench-marking Navy DIS technology for use in future DIS applications. To this end, an active fleet AEGIS cruiser, USS *Hue City* (CG 66), was a participant in STOW-E.

BFTT is a closed loop, interactive simulation, tactical combat training system. It provides scenario generation and control, simulation of friendly and enemy forces, and stimulation of organic shipboard sensors, data acquisition, reconstruction, and operator performance feedback, as well as connectivity with external scenario control and communication with remote sites.

Significant benefits from participation included the revelation of some BFTT shortcomings, both design and performance, that will help the BFTT Program Office to make corrections and enhance flexibility. For example, BFTT performance began to degrade when it handled more than 100 entities. The BFTT Program Manager estimates 18 months' savings in development progress as a result of exposing the BFTT prototype to joint simulation in its early stages. The Navy's primary objective of demonstrating the potential to train personnel at all levels, from individual tactical console operators up through the Battle Group Commander, in a DIS environment, was met.

Terrain Database

The objectives of the ARPA Synthetics Environments Program include development of advanced technology to represent and generate digital terrain databases (TDBs) to support increasingly large and complex STOW.

The STOW-E synthetic environments consist of a family of interoperable TDB products that support distributed ground, air, and naval simulations linked via DIS protocols on the DSI. The Ground Operations TDB is the highest resolution terrain database containing transportation, vegetation, drainage, soils, building, and other key complex features of the terrain surface. It covers a geographic area 64 km by 84 km that includes Grafenwoehr and Hohenfels, Germany. The Air Operations TDB covers a geographic area of 232 km by 232 km in northern Bavaria that includes the Ground Operations TDB area. The Naval Operations TDB covers a geographical area 244 km by 244 km centered in the northern Mediterranean Sea. Automated TDB compilers were used to generate the various formats required by STOW-E simulation systems. Each of the compilation activities resulted in a database in one of the following formats: SIMNET or Flight visual simulation; "Vistaworks"; SAF; Plan View Display; Management Command and Control console; or BBS raster files.

Modular Semi-Automated Forces (ModSAF)

What If Simulation System for Advanced Research and Development (WISSARD) employed Modular Semi-Automated Forces (ModSAF) in support of STOW-E. WISSARD also provided Intelligent Forces (IFOR), F-14 simulators, and an F-18 simulator to the STOW-E demonstration.

ModSAF and IFOR Force Mix entities included the following types: F/A-18, F-14, MiG-29, KS-3 (vehicle approximated by an A-10), and airborne early warning and control system (AWACS).

The following are accomplishments of WISSARD manned simulator operation during STOW-E: First formation flight with actual aircraft, manned simulators, and computer-generated forces; Communication link with "Hawkeye" Cherry Point TACTS Range Control and with live aircraft; Formation flight/coordinated strike with F-16 trainer (Falcon Star) in Grafenwoehr, Germany, with air control provided by the Tactical Air Command Control Systems Facility (TACCSF) AWACS; Formation flight/coordinated strike (300-nm route) with the Patuxent River F-18 manned simulator, the WISSARD F-18 Basic Air Tactics Trainer (BATT), the TACCSF computer-generated F-15s, and all under TACCSF AWACS control; Formation flight on Armstrong Labs' F-16 simulators at the terrain database; and the 2E6 was able to fly with and/or against the F-16 Falcon Star from Germany, the F-16s out of Armstrong Labs, the F-18 Manned Flight Simulator from Patuxent River, and the F-15 from Kirtland AFB.

Given the stage of the development of the air model for ModSAF and the relative lack of attention it has received over years of ground maneuver SIMNET SAFOR and ground maneuver ModSAF development, ModSAF Air effectively provides the combat domain with a large number of air entities possessing basic offensive and defensive capabilities. It proved to be good for basic targeting and to elicit initial behaviors from flight crews.

Automated Intelligent FORces (IFOR)

IFOR stands for automated Intelligent FORces. Ideally, IFORs allow replacement of human control of selected units on the simulated battlefield by automated control without noticeably degrading the appropriateness of the resulting behavior. When there are not enough humans (and associated simulators) available to fully populate the battlefield, populating it with even "dumb" IFORs yields more realism than would leaving it inappropriately unpopulated. This may be a viable technology for use at STOW97.

IFOR goals for participation in STOW-E were to participate in a large-scale operational exercise, learn what is required for theater-level exercises, provide viable IFOR opponents for human and ModSAF forces, and to learn about what is required for more advanced IFOR opponents in air-to-air and air-to-ground combat.

Air-to-air missions were successfully performed against ModSAF and humans in the BATTs and the 2E6. The attempt was made to engage planes from other sites, but they never reacted to the IFOR planes, and would typically fall off the net before the IFOR planes could get off missile shots. The IFOR planes also participated in air-to-ground (bombing bridges, etc.) and air-to-surface (firing missiles at ships) attacks in which there were successful engagements with ground and surface targets from other sites.

There were a limited number of software failures with the most significant being the inability to fly over the terrain database where the ground battle was raging when it was populated with hundreds of tanks. There was no problem flying over the terrain database when it was not populated with tanks—this was tested when Europe was off-line.

Overall, viable IFOR opponents were provided; however, it was difficult to evaluate the "skill" of IFOR planes because of problems with the underlying simulation models. A disappointment was the number of IFOR vehicles that could effectively be run on a single machine during these engagements (maximum of four). This exercise demonstrated that artificial intelligence (AI) technology can be successfully used in an operational exercise.

TECHNIQUES

Experimental PDUs

In the development of STOW-E, a number of experimental PDUs were developed at the Naval Command, Control and Ocean Surveillance Center (NCCOSC) RDT&E Division (NRaD) and at the Naval Underwater Warfare Center to supplement those PDUs defined in the DIS protocol standard. The Application Gateway-to-Gateway Protocol was used to reduce the number of standard PDUs sent on the DSI. This reduction allowed for data to be exchanged between sites within an effective bandwidth of 1.05 Mbps (a limitation imposed on STOW-E by the DSI T1 telephone line).

Security

STOW-E was executed as a multi-security-level exercise. Unclassified, US1, and Secret No-Foreign simulation sites were linked together over the DSI during STOW-E via one-way data links. Motorola's Improved Performance Network Encryption System (INES) was used to provide National Security Agency approved encryption at the secret level between classified sites. Modifications to existing network architecture allowed classified STOW-E sites to view and interact with entities generated at unclassified sites, in a limited way. Unclassified sites were unable to see or interact with any entities generated by classified sites.

The security guard worked as planned, designed, approved, and engineered. Early recognition of security issues and appropriate early and thorough action to mitigate security risk were instrumental in making security a non-issue for STOW-E. However, for future STOW demonstrations/exercises, the INES and the guard should be reviewed to determine if they are adequate for large and more complex exercises. They probably are not sufficient for STOW97.

Tactical Communications

The purpose of the Support and Tactical Communications was to provide the nondata communications support required for STOW-E. The nets were organized to simulate Tactical Radio Nets that would be found in use by the Tactical units simulated. This operation was accommodated by providing audio teleconference calls to replicate the nets, using Defense Switched Network (DSN) and Federal Telephone System (FTS) bridges. DSN was used for all conference calls involving overseas subscribers. FTS was used to support all CONUS-only conference calls. MCI Forum was available for backup. DSN was used because of cost considerations, and because FTS does not cover CONUS calls.

None of the circuits were covered; hence, the voice communications were "in the clear." In some instances, had secure voice been provided, more realism could have been achieved. However, for STOW-E, the cost vs. value was not beneficial. Use of the DSN caused pre-emption in some cases, which interrupted operations. Yet overall, pre-emption on the DSN was minimal (10 to 15%).

Technical Control

This area of responsibility entailed functions relating to the operation of STOW-E hardware and software located in the STOW-E Exercise and Analysis Facility (SEAF) at Grafenwoehr, Germany, and at participating sites, with the exception of communications and data analysis functions.

SEAF Technical Control was defined by the stations manned during STOW-E. These stations were Technical Control Manager, Technical Control Supervisor, Network Supervisor, DSI Operations Engineers, Application Gateway Engineer, Net Visualizer Analyst, Stealth Operator, Army Site

Status Projection Operator, Navy Site Status Projection Operator, Air Force Site Status Projection Operator, Technologies Status Projection Operator, Stealth 3-D Naval Shipping Operator, Stealth 3-D Navy/Air Force Operator, and DSI Network Status Projection Operator. For sites other than the SEAF, stations staffed will be as required by the size, equipment, and scenario involvement at each particular site.

For STOW97, this technique is necessary but will need to be customized by adding or subtracting stations reflecting the complexity of specific program/project objectives and goals. Factors of resource availability, number and technical maturity of sites, expected external interest levels, and joint aspects will determine the number of technical control stations.

Data Collection and Analysis

STOW-E analysis was divided into three areas: technical analysis, real-time and after-action scenario review, and operational analysis. Technical analysis addresses the performance of the DSI network, and the various systems and simulations operating on the network. Real-time and after-action scenario review assess the execution of the military scenario. Operational analysis addresses the effectiveness of the military training of the demonstration.

Data analysis efforts are focused on technical issues. Technical analysis includes the assessment of the performance of the Application Gateway (AG), the characterization of DIS traffic, and the estimation of delays across the network. The individual site DIS data log files are available to support military after-action reviews. Merging individual site files to construct complete, ground-truth log files for selected portions of STOW-E is on-going. This composite file will also support military after-action review. Operational analysis is being conducted by the 7th Army in Grafenwoehr, Germany, as well as Navy and Air Force designated analytical efforts, such as the Center for Naval Analysis.

The NRaD DIS Data Logger (DLogger) was used to record the DIS traffic during STOW-E. The DLogger records DIS PDUs along with a time-stamp corresponding to when the PDU was detected on the LAN by the DLogger. Data was recorded on the local simulation LAN at each STOW-E site. In addition to recording simulation LAN traffic, the two black sites, Ft. Rucker and SIMNET, logged data on the WAN side of the AG. The SEAF, in Grafenwoehr, Germany, also logged selected LAN and WAN network traffic using SGI's Network Visualizer software.

Characterization of DIS traffic loads is critical for network bandwidth allocation. DIS simulation load is a function of the simulation system, the number and types of entities being generated, the entities' levels of activity, and the dead-reckoning algorithm being used. DSI network delay will be estimated for selected segments/periods of the STOW-E exercise. STOW-E results for technical performance in this area are proving to be very time-consuming; therefore, a separate report will be published.

Test and Integration

Test and Integration covers the STOW-E test efforts from April through November 1994 including STOW-E planning meetings, Subsystem Integration Tests, Review and Planning meetings, Functional Validation Tests, System Integration Tests, and the STOW-E technology demonstration.

A preliminary test requirements list was developed using the STOW-E System Requirements Document as a starting point. Exit criteria and measures of success were developed specifically for each requirement. Schedules were developed and maintained to show upcoming events, major concurrent

military exercises, scheduled site participation, and site DIS node installation status. Master schedules were generated and displayed at NRaD and were used as the basis for test planning and coordination of associated activities. A trouble report process was incorporated into the test effort. Activity Logs were kept with as much detail as practical for the log keeper. At the end of each test period, a test report was written and distributed.

When STOW-E was completed, over 50 trouble reports remained. These trouble reports must be addressed before there are future demonstrations/exercises.

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Figures

Tables

1.0 INTRODUCTION

The Synthetic Theater of War - Europe (STOW-E) was a joint research effort run concurrently with ATLANTIC RESOLVE 94, a joint service training exercise. STOW-E was conducted 4 to 7 November 1994, with an After-Action Review on 8 November 1994. Many technologies and techniques were researched and integrated to enable live, virtual, and constructive simulation systems to be integrated into a seamless warfighting environment that will aid future warfighters in training that will hone the skills required in a tactical environment.

1.1 PROJECT GOALS

1.1.1 ARPA Goals

The principal objective from the perspective of the Advanced Research Projects Agency (ARPA) is to develop a Synthetic Theater of War (STOW) to demonstrate the feasibility and utility of Advanced Distributed Simulation (ADS) as a realistic, cost-effective tool for joint service training and rehearsal, and to support service acquisition programs. An additional objective is to transition ADS technologies for use by the joint service communities. STOW-E served as a first "stepping stone" on the path to STOW.

1.1.2 Army Goals

The specific goal of STOW-E , from the U.S. Army perspective, was to provide an interim capability to support training by using existing virtual world simulators, constructive model simulations, and instrumented vehicles. The use of Distributed Interactive Simulation (DIS) protocols, interface capabilities, and the Defense Simulation Internet (DSI) was to provide operational commanders an opportunity to train with fewer of the artificialities normally associated with previous efforts to manually link such systems.

1.1.3 Navy Goals

The U.S. Navy project goal was to demonstrate a potential for fleet training, in a DIS environment, of all echelons from the battle group commander to tactical console operators. Navy participation was guided by three overriding considerations: (1) involvement to be doctrinally correct and operationally relevant, in line with "From The Sea" and forthcoming Naval Doctrine Pub - 1; (2) the Navy to share and contribute in scenario development; and (3) training to be demonstrated with fleet operators participating in all man-in-the-loop simulations.

1.1.4 Air Force Goals

The U.S. Air Force goal was to gain experience with the training capabilities that STOW-E technology can support, and to provide input into future development of technology. Air Force participation in STOW-E was limited to sites where available technology could support air operations that were tactically relevant, doctrinally sound, and that could make a visible contribution to operations being conducted.

1.1.5 DMSO Goals

The Defense Modeling and Simulation Office (DMSO) goal was to expand DoD's simulation infrastructure, broaden the use of modeling and simulation to support DoD functional requirements, and work toward interoperability of modeling and simulation tools and applications.

1.2 CONCEPT

Under the STOW concept, DIS-compliant simulation systems may enter into the network and participate in STOW exercises. This might include DIS-compliant simulators such as aircraft, ships, missiles, tanks, and other weapons systems of the Army, Navy, and Air Force working together to make a more realistic exercise.

During STOW-E, live instrumented vehicles at the Combat Maneuver Training Center (CMTC), Hohenfels, Germany, were linked with the Brigade/Battalion Battle Simulation (BBS) System and the Simulation Network (SIMNET) simulators at Grafenwoehr, Germany. This permitted a heavy ground combat brigade, consisting of three battalion task forces, command and control elements, combat support (CS) and combat service support (CSS) elements of the brigade, to train together. Each battalion task force made use of one of the three simulation systems to conduct its assigned tactical missions in a brigade-sized battle and to deploy and fight at the entity level. Through the use of a DIS Interface Unit, they were able to affect cross-boundary operations using direct and indirect fire, as well as air assets. The brigade commander had the ability to influence the outcome of a close fight by planning and executing operations against enemy formations in the areas "beyond visual range."

Naval forces included battle group power projection operations in support of Army brigade-size forces, and consisted of air, surface, and subsurface units. Included in the seven Navy sites that participated in battle group interactions across the Defense Simulation Internet were a live AEGIS cruiser, instrumented live aircraft, and both man-in-the-loop and computer-generated simulations.

Air Force participation consisted of manned simulators at five sites flying composite missions in support of the joint operations.

1.3 SCOPE

STOW-E was co-sponsored by ARPA, DMSO, and the U.S. Army Europe, 7th Army Training Command, Grafenwoehr, Germany, with supporting U.S. Navy and Air Force participation. The focus of STOW-E was the integration of:

a. Live instrumentation with the Combat Maneuvering Training Center - Instrumentation System (CMTC-IS), Hohenfels, Germany.

b. Constructive simulation with BBS using the BBS-AIU with Semi-Automated Forces 4.3.3 (SAF 4.3.3) simulator, Hohenfels, Germany.

c. Virtual simulation with the SIMNET and with the Semi-Automated Forces (SAF 3.10) simulator, Grafenwoehr, Germany.

d. Virtual simulation with the Air Network (AIRNET) simulator and with the Semi-Automated Forces (SAF 4.3.3) simulator, Fort Rucker, AL.

e. Technical and exercise control at the STOW-E Evaluation and Analysis Facility (SEAF), Grafenwoehr, Germany.

f. Live instrumentation with the Tactical Air Crew Training System (TACTS), Marine Corps Air Station (MCAS) Cherry Point, NC.

g. Virtual simulation with the SSN 688 Submarine Trainers at the Naval Undersea Warfare Center (NUWC), Newport, RI.

h. Virtual simulation with the What If Simulation System for Advanced Research and Development (WISSARD), and with the Modular Semi-Automated Forces (ModSAF) simulator, NAS Oceana, VA.

i. Virtual simulation with the Battle Force Tactical Trainer (BFTT) at the Fleet Combat Training Center Atlantic (FCTCLANT), Dam Neck, VA.

j. Live instrumentation with USS *Hue City* (CG 66), an AEGIS cruiser, berthed at Naval Station, Mayport, FL.

k. Virtual simulation with the E-2C and F/A-18 simulators at Naval Air Warfare Center - Aircraft Division (NAWC-AD), Naval Air Station (NAS) Patuxent River, MD.

l. Virtual simulation with BFTT TAC-III consoles simulating an AEGIS combat suite at the AEGIS Computer Center, Naval Surface Warfare Center - Dahlgren Division (NSWC-DD), Dahlgren, VA.

m. Virtual simulation with the FALCON STAR manned simulator at Spangdahlem Air Force Base (AFB), Germany.

n. Virtual simulation with cockpit simulators at the USAF Armstrong Laboratories, Mesa, AZ.

o. Virtual simulation with USAF cockpit simulators at Royal Air Force (RAF) Lakenheath, England.

p. Virtual simulation with cockpit simulators at the USAF Theater Battle Arena, the Pentagon.

q. Virtual simulation with cockpit simulators at Theater Air Command and Control Simulation Facility (TACCSF), Kirtland AFB, NM; and

r. Monitoring with the Institute for Defense Analysis (IDA) Viewport, Arlington, VA.

Figure 1-1 illustrates the scope of STOW-E.

1.4 DOCUMENT OVERVIEW

This document details the technologies and techniques developed for STOW-E. Included is a detailed description of each technology or technique along with achievements and lessons learned from the STOW-E demonstration. This document is organized into five sections. Sections 1.0 and 2.0 are the introduction and applicable documents sections, respectively. Section 3.0 contains aggregation/ deaggregation, scaleability, live/range instumentation, terrain database, modular semi-automated forces, defense simulation internet, and intelligent forces technologies. Section 4.0 contains experimental protocol data units, security, tactical communications, technical control, data collection and analysis, and test and integration techniques. Section 5.0 is a list of acronyms and abbreviations.

STOW-EUROPE

- ARPA, USAREUR
- EXERCISE IN CONJUNCTION WITH REFORGER '94
- ARMY: TRAINING
- AIR FORCE & NAVY: PROOF-OF-CONCEPT

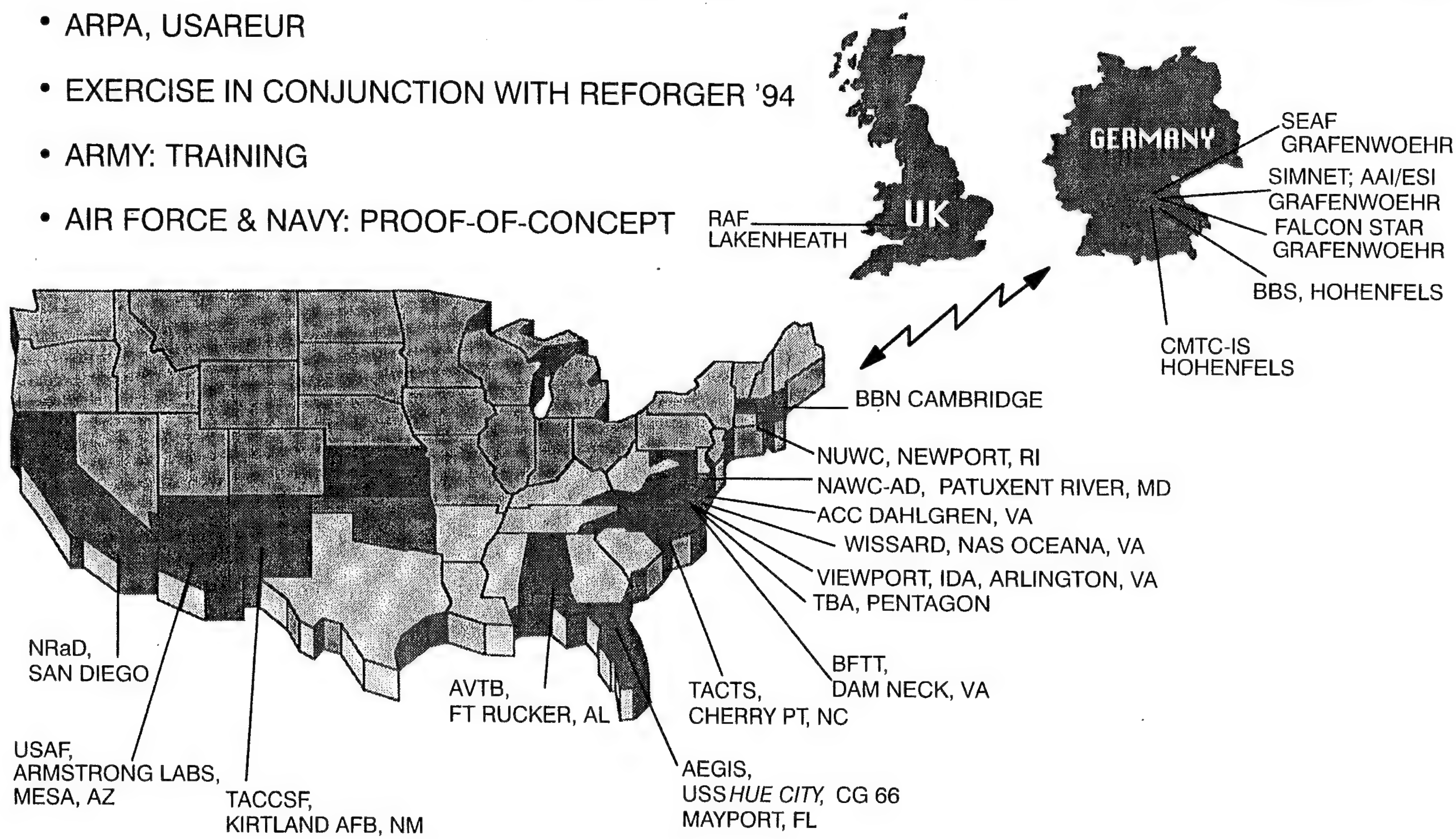

Figure 1-1. The scope of STOW-E.

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2.0 DOCUMENTS

Proposed IEEE Standard Draft: Standard for Information Technology - Protocols for Distributed Interactive Simulation Applications, Version 2.0, Third Draft, Institute for Simulation and Training, May 28, 1993.

3.0 TECHNOLOGIES

3.1 AGGREGATION/DEAGGREGATION

3.1.1 Background

Aggregation/Deaggregation was born from the attempt to link a constructive model, such as the BBS, which uses icons representing multiple individual entities, with a virtual model, such as SIMNET or DIS technologies, where all units are represented as individual entities. The problem facing the team was the development of methods for resolving the differences between these simulation environments, and presenting to the users of each simulation an interoperable system on a common battlefield.

3.1.2 Issues

The essential dissimilarity between these simulation environments needed to be resolved in several technical areas: aggregation/deaggregation (BBS units vs. DIS individuals), timing (BBS 15-second updates vs. DIS continuous updates), combat resolution (BBS "roll of the dice" Battle Damage Assessment (BDA) vs. DIS individual deterministic BDA), terrain database correlation (BBS 100-m grid resolution vs. DIS 30- to 120-m variable resolution), training audience and objectives (BBS Brigade/Battalion Commander and staff, and Combat Support/Combat Service Support vs. SIMNET Company/Platoon Commander and Combat/Maneuver), network bandwidth, and command and control.

3.1.3 Approach

To bridge the gap between the constructive simulation and the virtual simulators, an aggregation/deaggregation technology was created by integrating the Advanced Interface Unit (AIU) and the Semi-Automated Forces (SAF) engine. The AIU provided the interfaces between the BBS simulation and the SIMNET simulators, performed translation between DIS and SIMNET protocols, performed dead reckoning of DIS entities, and provided necessary functionality that was missing in the SAF. The SAF engine performed the actual modeling of the deaggregated BBS entities as individual vehicles and provided several basic maneuver and combat support functions.

To maintain this common, or seamless, simulation, the following basic ground rules were followed:

a. Provide the same tactical picture in the interoperating simulations at all times.

b. Preserve credibility of the tactical picture in time and space after repeated aggregations and deaggregations.

c. Resolve interactions (movement, visibility, engagement) in the higher fidelity simulation for that interaction and pass results back to the lower fidelity system to the extent possible.

d. Construct a virtual sphere of influence to regulate computer system and network capacities.

3.1.3.1 Aggregation/Deaggregation. For aggregation, user-defined mapping tables were established to map SIMNET individual vehicle bumper numbers into platoons that could be subsequently handled in BBS. For example, four SIMNET vehicles A11, A12, A13, and A14, would be mapped to one BBS unit (icon) 1/A/ARM-7. Location of the aggregate unit in BBS was calculated as the "center of mass" location for the SIMNET vehicles in that unit. For deaggregation, BBS units of varying sizes (between 1 and 20 vehicles) were passed as a unit to the AIU, which would then ask a SAF engine to create the correct number and type of vehicles in a specified formation. Also, aggregate Protocol Data Units (PDUs) were sent out on all BBS units.

3.1.3.2 Timing. To handle the time discrepancy, the information on deaggregated BBS units, including location, BDA, etc., that changed in the 15-second period was passed back to BBS for the next update.

3.1.3.3 Combat Resolution. The principle discussed above of performing functions in the higher fidelity model was applied to combat resolution. BDA is performed in SAF/SIMNET for those vehicles that have been deaggregated because of the higher fidelity of determining BDA at the individual vehicle level. Damage results from the combat action are passed back to the BBS operator as they occur. Personnel status is tracked via BBS algorithms, since SIMNET does not track personnel.

3.1.3.4 Terrain Database Correlation. Once again terrain discrepancies and Line-of-Sight (LOS) calculations were performed in the simulation with higher fidelity terrain (which is the SAF terrain). Also, a BBS digital database was built from the same source as the SAF terrain database to gain better correlation between the database features. SIMNET maps were provided to assist in the planning of movements for the BBS operators.

3.1.3.5 Training Audience and Objectives. The BBS training audience was the battalion and brigade commanders, and their staffs in their Tactical Operation Center (TOC); this audience normally concentrated on CS and CSS areas. In SIMNET, the training audience was the company and platoon commanders, and their tank crews; they focused on team training for maneuver and combat areas.

3.1.3.6 Network Bandwidth. Exceeding network and system capacity was a continual concern. Methods were developed to try to regulate the number of entities in the simulation so as not to exceed SAF engine capability or load the network unnecessarily. A Sphere of Influence (SOI) model was developed to help regulate the number of deaggregated BBS entities. Local Collision PDUs from SAF generated units were filtered out to prevent them from going onto the network and causing additional traffic. The filtering of incoming PDUs by the AIU, by site, helped keep the Local Area Networks (LANs) of SAF engines and Stealth from bogging down under high loads.

3.1.3.7 Command and Control. The BBS operator had certain control over his deaggregated unit. He could change speed, fire posture, engagement range, and formations. The particular formations that the BBS operator could give a unit, called opstates, were mapped to SAF command instruction sets to aid in command and control of a unit.

3.1.4 Benefits

The linkage was designed to exploit the strengths of both simulations, combining the command and control structure, and the combat support and combat service support functions of the BBS constructive simulation, with the combat functionality of the SIMNET virtual simulators. This allowed for simultaneous training from the brigade commander and staff, to the individual soldier. It is hoped that the techniques applied to this problem can also apply to the interoperation of other simulations.

3.1.5 Demonstrations and Exercises

Several exercises and demonstrations have been supported along the path to integration; most notable are:

MAR '94 FIRESTARTER Operational Exercise in Grafenwoehr. This was the first brigade-level exercise including the AIU (three Central Processing Units (CPUs)) and three SAF engines capable of 300 to 400 entities.

MAY '94 CINC USAREUR Demonstration in Grafenwoehr.

AUG '94 1AD (Air Defense) Operational Exercise in Hohenfels and Grafenwoehr.

SEP '94 STOW-E Functional Validation #2 Test in Hohenfels and Grafenwoehr.

OCT '94 SECDEF Demonstration in Hohenfels and Grafenwoehr.

NOV '94 STOW-E Operational Exercise in Hohenfels and Grafenwoehr. This brigade-level exercise included the AIU (five CPUs, shared memory) and nine SAF engines that when combined were capable of 1000 to 1100 entities.

3.1.6 BBS STOW-E Exercise

3.1.6.1 Goal. The goal of the Aggregation/Deaggregation project for STOW-E was to implement the BBS/SIMNET interface into an operational exercise and include interactivity with the CMTC Live Instrumented Range, thus providing the enabling technologies for aggregate-level constructive wargaming systems (BBS), individual virtual simulators (SIMNET), and individual live combatants (CMTC-IS) to interact in a joint training exercise.

3.1.6.2 Challenge. The challenge was to provide an operationally useful interface allowing seamless integration of each domain as operational missions are performed. This would include a CMTC Battalion Task Force (BTF) for both Blue Forces (BLUFOR) and Opposing Forces (OPFOR) in the CMTC Sector; a BBS BTF for both BLUFOR and OPFOR in the BBS Sector; and a SIMNET BTF with BBS CS/CSS support forces for BLUFOR and a BBS BTF for OPFOR in the SIMNET Sector. The BBS/SIMNET interface was to support the missions, as required, between the sectors.

3.1.6.3 Configuration. Figure 3-1 depicts the BBS/SIMNET STOW-E architecture. The BBS/SIMNET link was established at the BBS Warlord site at CMTC Hohenfels, Germany. The system consisted of nine SAF engines (Silicon Graphics, Incorporated (SGI) Indy's) running SAF 4.3.3 software and using the STOW-E terrain database (stowe-0105 ctdb) for modeling the BBS deaggregated units; one AIU (Versa Modula Europa (VME) card cage with five CPU cards, Shared Memory card, and Hard Disk) with thin/thicknet connections to BBS, SIMNET, and DIS networks for providing the interface between the domains (including the DIS/SIMNET protocol translation and the aggregate PDU generation); one ModSAF 1.2 Plan View Display (PVD) (SGI Indigo2 Extreme) for displaying and monitoring the DIS traffic; one Development System (SGI Indigo2 Extreme) for data logging and monitoring entity counts; one SAF 4.3.3 PVD (SGI Indigo2 Extreme) for Stealth control; one Stealth View (GT110) for pre-exercise movement setup and movement monitoring during the exercise; and three terminals (VT320s) for SIMCON control.

The SAF Engines, SAF 4.3.3 PVD, two AIU SIMNET CPUs, and Stealth View were on a separate thicknet LAN using SIMNET protocols. The VT320s, one AIU BBS CPU, and 17 BBS Workstations were on a separate thinnet LAN using BBS specific protocols.

The ModSAF 1.2 PVD, Development System, and two AIU DIS CPUs were on a separate thinnet LAN using DIS protocols.

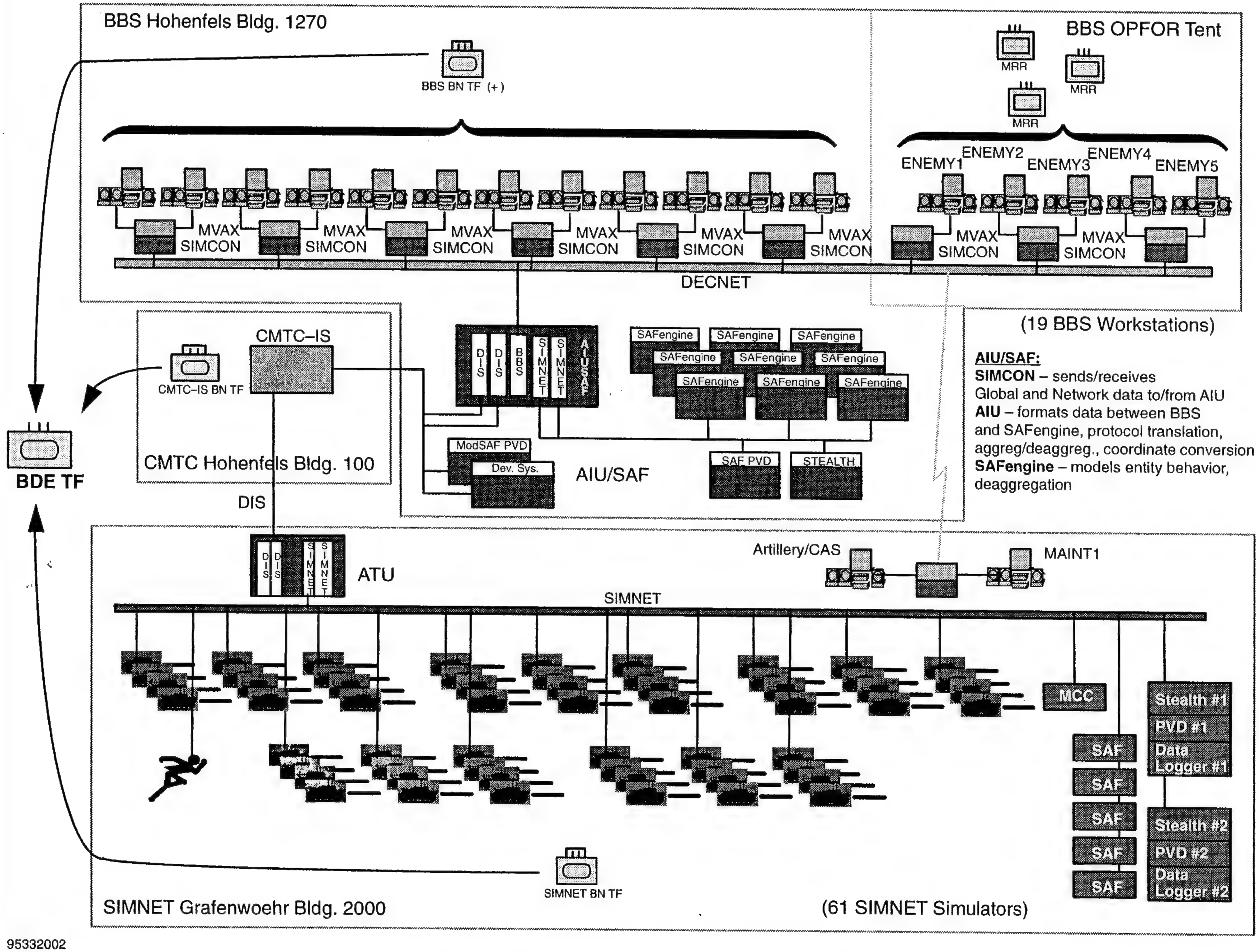

Figure 3-1. BBS/SIMNET STOW-E architecture.

The 17 BBS Workstations were divided up as 12 BBS Workstations to support the BLUFOR operation in building 1270, and 5 BBS Workstations to support the OPFOR operation in a temporary tent co-located with building 1270. An additional 2 BBS Workstations were located in the SIMNET building 2000 in Grafenwoehr, Germany, to support BLUFOR operations. These workstations were connected via modem to building 1270 and were used for CS/CSS operations in support of the SIMNET task force in the SIMNET sector. The BBS STOW-E terrain database was the digital database used during the exercise. SIMNET maps were put together to allow BBS operators to visually correlate movements on their BBS maps with the SIMNET maps.

The DIS LAN was connected to a fiber-optic network that ran to a bridge in CMTC building 100, through Well Fleet routers to a similar setup at the SIMNET building 2000. A subset of the AIU, called the Advanced Translator Unit (ATU) was setup at the SIMNET site to convert the incoming DIS and outgoing SIMNET traffic for the 60 SIMNET Tank simulators and the one Dismounted Infantry (DI) simulator at the SIMNET site. The ATU consists of a VME card cage with four CPU cards with interfaces to the SIMNET and DIS networks.

Security measures were enforced for the entire building 1270/tent complex. A fence was constructed around the perimeter with rolls of concertina wire as well. A guard was posted just inside the gate at 1270 to check badges and issue visitor passes. A guard was also posted inside the OPFOR tent for similar duties.

3.1.6.4 BBS STOW-E Achievements. BBS/SIMNET interface achievements include the interactions between the constructive, virtual, and live domains as described here:

a. BBS tank platoons being controlled by BBS soldier operators in Hohenfels engaged and destroyed SIMNET tank simulators being driven by soldiers in Grafenwoehr. The BBS operator sees a platoon icon representing a SIMNET platoon on his workstation.

b. BBS tank platoons fired on CMTC-IS real tanks being driven in the "box" (Hohenfels combat maneuver training area). The interface precluded destruction of real entities by virtual entities.

c. BBS artillery missions were fired, subsequent "shot" and "splash" were heard over the communication network as the artillery hit the designated locations. BBS artillery effectively destroyed and/or mobility killed SIMNET tank simulators.

d. BBS minefields were emplaced and SIMNET tank simulators were able to view the minefield markers and detonate the mines (there is still a problem with the lethality of the mines, although there have been a few mobility kills and destroyed vehicles). BBS minefields were breached and the subsequent breach markers were observed in SIMNET.

e. SIMNET tank simulators were able to pull up next to BBS fuel tankers and cargo trucks and receive the appropriate fuel and ammo resupply.

f. BBS aircraft (fixed and rotary wing) engaged and destroyed SIMNET tank simulators.

g. BBS air defense vehicles engaged and destroyed helicopter simulators being flown at Ft. Rucker, Alabama, and engaged and destroyed the Falcon Star (F-16) simulator being flown at the STOW-E Evaluation and Analysis Facility (SEAF) in Grafenwoehr.

h. SIMNET tank simulators saw BBS aggregate units as individual vehicles and engaged and destroyed BBS individual vehicles. The BBS operators saw that they had lost vehicles as a result of the engagement, thus reducing the combat strength of the BBS aggregate unit.

i. Ft. Rucker helicopter simulators saw BBS aggregate units as individual vehicles and engaged and destroyed BBS vehicles. Ft. Rucker helicopters also engaged and destroyed BBS aircraft including friendly fire on a BBS A-10.

j. Falcon Star simulator engaged and destroyed BBS vehicles.

k. CMTC-IS fired artillery and destroyed deaggregated BBS vehicles.

Another achievement was the ability to meet last-minute changing requirements in order to use the system (with its faults) in an operational training exercise that was deemed a success.

A sometimes overlooked BBS/SIMNET achievement was that the interface is actually an interface to DIS, allowing interactions with any other DIS-capable system.

The final success was the ability to upgrade the interface from testing with company-size forces in February '94 to brigade-size forces for STOW-E. This included having the ability to expand to multiple SAF engines (10 is the maximum to-date); handling over 1000 entities; sending out AggPDUs to include information on all BBS units (not just the deaggregated units); expanding to over 20 BBS workstations; improving recovery time by a factor of 10; and making significant architecture changes of adding more processor cards, shared memory, and a hard disk for the terrain database. These were relatively quick changes to expanding requirements and are considered significant and important accomplishments.

3.1.7 BBS STOW-E Issues

3.1.7.1 Fixes and Fine Tuning. Several changes were made since the program review in September 1994. They are discussed as follows:

a. *Internal UO protocol:* This fix was implemented in SIMCON and the AIU to send out Uninstantiated Objects (UOs) on all objects when coming up so that the Brigade Operations Display and AAR System (BODAS) would get all UOs before game start.

b. *Bumper Numbers extension:* This was expanded to include unique marking text from CMTC-IS and Falcon Star. The extension maps to the marking field in the Entity State PDU (ESPDU) and now equals DIS marking field size.

c. *Translation (ATU and AIU):* An unused field of the Detonation PDU was used to transfer information (not currently passed by DIS) for the SIMNET Impact PDU. This was done to get better weapons effectiveness for Hellfire and 30-mm. The parameters passed were trajectory (Hellfire), directionality (30-mm), momentum, and energy. The three impacts per fire, a problem due to the unique way SIMNET was handling impacts through the association PDU, was fixed. The problem of receiving some "unknown to SAF" munitions mappings was fixed by mapping the unknown munitions to known SAF munitions. Some parameters in the SIMNET Vehicle Appearance PDU were not being passed through DIS. These were fixed by setting the vehicle class to get the BMP turrets to rotate in the direction of firing and by setting engine speed to get the helicopter rotors turning.

d. *SIMCON:* The direct fire message was not being generated; this was corrected. Some new reports were created including internal error reporting for debugging purposes and a listing for the BBS operator to correlate BBS Unit IDs with BBS Unit Names and with their mapped SIMNET or DIS bumper numbers. A UO delay was added to allow the UO to be downloaded and sent out first before units get instantiated. The delay is currently set at 1 minute.

e. *SAF 4.3.3*: SAF terrain obstacles (tree canopy avoidance, water hazards, and soil types) were removed (or "turned off") to meet the criteria of moving BBS units through an area and meeting specific phase line times. There were numerous bugs fixed in SAF 4.3.3 that formerly caused it to crash. No SAF core dumps were noticed during STOW-E.

f. *BBS OPFOR Tent (LAN Fix):* The OPFOR tent was put up after Functional Validation #2. After having severe movement problems, it was discovered that 60 to 75% of the data was being lost going to the tent. A DEC DELNI (a multiplexing device for BBS) was causing the bottleneck. After it was removed from the loop, 100% of the data got through.

g. *Stealth View:* The Stealth GT110 was an immense help, and its addition to the BBS setup at Hohenfels provided invaluable debugging information on why vehicles were getting stuck. It also provided a great visual cue for preparing movement legs for BBS unit movement and for monitoring BBS units moving through the terrain during the exercise.

3.1.8 AIU/SAF Issues

The following is a discussion of issues that came up over the final 4 to 6 months.

3.1.8.1 SAF Delete Entries. The SAF 4.3.3 code had a bug that does not allow deletion of entries from a hash table. Thus, the hash table eventually fills up (to a maximum of 2048 entities) and then the process stops. This was discovered only 2 days prior to STOW-E. Prior to that, SAF crashes were thought to be solely related to excessive numbers of entities. During the exercise, an attempt was made to maintain a stable SOI by using the relocatable SOI feature of SIMCON. This seemed to work to a certain degree, but eventually the table would still fill up. The size of the table was monitored to predict when the system would go down and to take advantage of any lulls or pauses in the exercise in order to restart. Possible fixes to avoid a crash include allowing deletion of entries, resizing the hash table, or generating a warning for the operator as the table fills. (Short term)

3.1.8.2 SAF Movement. There were several problems with SAF movement:

a. The aircraft tended to wander off of their courses frequently for no apparent reason. More investigation is required to determine why it is happening and what can be done about it. (Mid term)

b. Every time the Travel-On Road function was implemented, SAF engines crashed. This problem also needs more investigation. (Mid term)

c. Water hazards have always been a problem. Vehicles got stuck, eventually got through, and then turned around and went right back into the water. This resulted in unacceptable time delay and confusion for the BBS operators. BBS technicians have removed most of the unfordable water hazards from their own BBS digital database. For STOW-E, the water hazards were removed from the SAF. (Mid term)

d. Tree canopies also caused problems. One was a "cul-de-sac" problem: an indention in a canopy where the vehicles seemed to keep looping and never get out. Other problems were with the roundabout way of getting around canopies and with the troubles caused when canopies were very close together. These problems caused severe movement problems and time delays for BBS units; thereby requiring that the tree canopy avoidance algorithms in SAF were turned off. (Mid term)

3.1.8.3 SAF CS/CSS. The AIU handled red artillery missions, all artillery dispersion, and all resupply functions, not the SAF. This functionality is, or will be available, in ModSAF. (Mid term). Also, resupply vehicles had unlimited supplies; this could be fixed in the short term by tracking in the AIU. (Short term)

3.1.8.4 SAF Minefields. At times the minefield markers appeared to look different on different Stealths. This may be due to the large quantity of mines and markers, the update rate of the markers,

or even the loading of the different Stealths. (Mid term). Also, the breach markers can be used as implemented to mark a breached area, but the orientation of the markers is wrong. There may be no solution to this problem. (Long term)

3.1.8.5 SAF Terrain Database. Entities hit steep, vertical walls, got stuck, and then start flipping around. Perhaps there was a problem with the avoidance algorithm of entities and vertical slopes, or perhaps the problem is the actual tdb or ctdb, or a combination. (Mid term). Also, it would be beneficial to be able to easily turn off certain obstacle avoidance algorithms to meet specific operational objectives. (Long term)

3.1.8.6 SAF Engagements. Marksmanship was reduced to 0.5 for OPFOR during STOW-E, but there was no control over target acquisition. It appears that as soon as LOS was established, the SAF vehicles acquired the target(s) immediately and began firing. This was unrealistic for the SIMNET vehicles; thus the target acquisition parameter needs to be adjustable. It was also noted that detection ranges for SIMNET and for BBS need to be the same. (Mid term)

3.1.8.7 SAF Entity Load. The capability for more SAF entities is needed. Right now, moving to ModSAF will yield fewer SAF entities. (Long term)

3.1.8.8 AIU/SAF Unit Names. A naming convention for units between the different domains needs to be established. The current naming conventions for CMTC-IS and BBS are different. There is still a problem with BBS's aggregate units. Some are split out after the game has started. This creates problems with systems such as BODAS that are trying to track vehicles at an individual level. A method of naming the BBS individual vehicles and handling the split units needs to be investigated and implemented, probably in the AIU, using marking text and a cross-reference table. (Mid term)

3.1.8.9 AIU/SAF Reallocation. If one or more SAF engines crash, they can be restarted and be back running in seconds. However, if a SAF engine crashed hard, the entire system needs to be restarted. A function could be added to transfer entities to another SAF engine, if that SAF engine could handle the additional load. (Mid term)

3.1.8.10 AIU/SAF SOI Calculations. The SOI calculation should be moved from SIMCON to the AIU. This would free up some of the processing load created by SIMCON. At the same time, the efficiency of the SOI calculations could be increased by using a sorted array of units, and the methodology of the SOI could be used to reduce the total number of entities and to decrease the cascading effect. (Mid term)

3.1.8.11 AIU Memory. The memory on the CPU card is near capacity. Other CPU cards with more memory could be purchased, or other alternatives could be investigated. Also, when CMTC-IS entities were not filtered out, the flood of PDUs resulted in fragmentation of memory on BBS card 2. There was plenty of memory, but no one piece was big enough to hold the rather large unit data structure (~12 kbytes). Modifying the unit data structure to be variably sized and malloc'ed in pieces instead of as one large chunk, would enable the AIU to handle a larger number of entities coming in from DIS. (Mid term)

3.1.8.12 AIU/SAF Design Issues. As the capability of the system continues to be stressed and expanded, there may need to be a re-evaluation to determine if the current design can reach the next plateau. While the capabilities were rapidly increased from FireStarter to STOW-E, the system may be reaching its limitations. Other alternatives may be needed to be investigated. (Mid term)

3.1.9 BBS/SIMCON Issues

Most of the issues listed below are not problems with the current system, but suggestions on how to improve the system. Interaction with BBS was limited in several areas due to the restriction of not being able to change BBS source code. In fact, no changes to the BBS code was made for STOW-E. Some of the information to the BBS operator therefore did not flow as smoothly as desired. The following is a discussion of the most current issues and limitations:

a. *BBS 3.0.* Convert SIMCON code to BBS 3.0 in future. (Short term)

b. *BBS BDA.* Perform BDA for artillery and minefields in SAF for BBS units in the SOI. Let BBS complete the BDA for SAF initiated damage. (Mid term)

c. *BBS Movement.* Perform movement calculations only in the SAF (not in BBS) for BBS units in the SOI, to reduce the jumping of icons in BBS. Review the problem with units not following movement orders. (Mid term)

d. *BBS Unit Names.* Adopt identical naming conventions across the various simulation domains. (Mid term)

e. *BBS Enemy Workstations.* Increase the number of OPFOR workstations in a game to more than five (10 minimum). (Mid term)

f. *BBS Total Icons.* Increase the total number of icons in a game to above 750 (1000 minimum). (Mid term)

g. *BBS Deagg Flag.* Create a deaggregate flag and keep it in the BBS database to track whether a unit is deaggregated or not. Could use the deagg flag to signal functions to suppress calculations. (Mid term)

h. *BBS Cease Fire.* Allow the BBS commander to control cease fire for his units while in the SOI. Currently, it is done by setting the engagement range to zero and locking cease fire "on" in BBS. (Mid term)

i. *BBS Shift.* Improve the BBS commander's ability to move stalled units. BBS should monitor movements for units in the SOI. The stalled unit should be flagged and SHIFT be made available to the BBS commander. The SHIFT function does not currently work even with a BBS-only exercise. (Mid term)

j. *BBS LOS.* Suppress the LOS/Detection calculations between BBS pairs that are in the SIMNET SOI. (Mid term)

k. *BBS MTBF.* Suppress the Mean Time Between Failure calculations for a BBS unit in the SIMNET SOI. (Mid term)

l. *BBS Personnel Counts.* Personnel damage assessment was not always accurate. It would be better to develop a way BBS could take external damage and process it according to the damage received. (Mid term)

m. *BBS Maintenance and Supply.* Allow Maintenance and Supply missions to be done from all workstations. During STOW-E, such missions had to be conducted from specific workstations because BBS did not send the appropriate messages from all stations. (Mid term)

n. *BBS Alerts.* The alerts generated by the BBS units in the SOI should be reviewed. Some alerts generated by BBS should be removed (i.e., detection alerts), and should be generated from data received from the SAF. Some redundant alerts should be paired down (i.e., receiving direct fire). (Mid term)

o. *BBS Performance Considerations.* Several methods of tracking BBS network and memory activity were developed. Each method brought increasingly better performance, but none was very efficient. More work needs to be done in this area. Some of the problem was addressed by using MicroVAX 3100-90s, which greatly increased response time. Any platform slower than a MicroVAX 3100-40 would not have acceptable performance.

p. *BBS Terrain Database.* The BBS STOW-E digital database was not consistent with the previous BBS digital database for that area, although correlation appeared within tolerances. Obstacles were scattered throughout the database with many discontinuities.

3.1.10 BBS STOW-E Entity Counts

Entity counts fluctuated depending on the training mission. Total entities ranged from 1163 to 1637 entities. BBS-generated entities ranged from a low of 535 entities to a high of 1017 entities. The BBS 735 icon count on the Movement-To-Contact mission was larger than any other BBS game that BBS Warlord had ever run.

UOs were also being sent out, and tools were developed on November 4th and 5th to help monitor uninstantiated objects and the total number of entities they represented. The total number of BBS entities being represented by UOs plus the total number of BBS entities on DIS equaled the total number of entities in the BBS database for that mission.

BBS had 2800 entities ready to map through AggPDUs, and if everything in the BBS database had been split out it would have equaled 4400 entities. Upon finding out that BODAS had room for only 2500 (external) entities, the entities were reduced to under 2500 (i.e., 2182 on 6 November), and the operators were told that no splits were allowed. As it turned out, there were probably less than 100 new vehicles created by splits each day, but other conditions existed that pushed the count to 2500 plus.

One such condition was that anytime something went in and out of the SOI, it took up more slots, and anytime a SAF engine went down, more slots were taken. Thus, in order to regulate the fluctuation of entities, the relocatable SOI was placed at specific locations where engagements would occur, rather than immediately mapping in all DIS vehicles. This procedure was a successful attempt to keep from filling up the SAF engine hash table and to help BODAS from filling up its slots.

Fast movers (aircraft) caused the most concern in fluctuating entity counts. There was some control over the fluctuation with respect to external fast movers (Rucker and Falcon Star), but there was no control over BBS fast movers who became the biggest problem.

Also, having the BBS Blue/BBS Red battle first, and then moving the SIMNET battalion through the rear echelons of the BBS Blue battalion, caused a lot of seemingly unnecessary instantiations that began filling up tables prematurely. Switching the BBS Blue battalion and the SIMNET battalion may have worked better; however, it may not have satisfied the tactical mission.

The SAF engine was the limiting factor in entity-count capacity. To allow play in both the BBS and SIMNET environments without taxing the capacity of either the SAF engines or the networks, a method of limiting the number of BBS entities in SIMNET play was developed called the SOI model. The supposition was that a simulator would have an SOI around it. Any BBS unit that came within that SOI would then be deaggregated. When that same unit was far enough away, it would be reaggregated. A padding was set up to keep the unit from "riding" the SOI boundary and constantly being deaggregated and then reaggregated. Trying to fine-tune this SOI value was not very effective

because differing weapon platforms could fire from distances ranging from 1500 m to 10 km, so a variable SOI value was developed. Finally, the SOI boundary value was calculated as follows:

SOI entry = (BBS maximum range) + (possible distance covered in 5 seconds) + padding,

SOI exit = SOI entry + exit padding,

where the padding for both the entry and exit of the SOI was user-definable and changeable during the exercise. A series of "relocatable" SOI values was defined allowing the user to create virtual "points of interest."

Even with the SOI, cascading of deaggregated units was substantial, because a deaggregated BBS Blue unit would subsequently deaggregate a BBS Red unit if it were close enough, and so on.

3.1.11 BBS STOW-E PDUs

The AIU and ATU used the following PDUs:

Entity State (ES); Fire; Detonation; Collision; Resupply (ServiceRequest, ResupplyOffer, ResupplyReceived); Marker; SIMNETStealth; and Aggregate PDUs.

The Collision PDUs from our site were not transmitted onto the DIS network in an effort to reduce the packet load sent to the SIMNET site.

Aggregate PDUs were also being sent that described the entities that the BBS units represented. Modifications to the Aggregate PDU included the addition of the Entity Appearance field so that members of an aggregate unit could be described more fully. This enabled portraying combat power of an aggregate unit being generated by BBS. The aggregate Unit Name field was added to pass along the hierarchical name that the BBS operators used when referencing an aggregate unit. The Aggregate PDUs were also being used by a simulation developed by Coleman Research Corporation and by BODAS.

3.1.12 BBS STOW-E Lessons Learned

There were many significant lessons learned during STOW-E:

A Functional Validation (FV) dry run at least 1 month prior to the exercise is essential.

There should be no new system requirements imposed on a system after the FV. There were several requirements that continued to change even through FV3, making it extremely difficult to comply.

All systems that are going to be used or have a major impact on the exercise should be tested during the FV.

The Operational user needs to test the system during the FV in the same manner he will use it for the final exercise. Not having the same BBS OPFOR and BLUFOR teams for the dry run (FV2) as for the exercise, and not having the full complement of soldiers in BBS and SIMNET simulators moving around, resulted in not being able to stress the system appropriately before the exercise. Having the OPFOR commander (who had no experience with the system) use the system for the first time only a week before the exercise, almost resulted in no system being used.

The criteria that determine whether the system will be used need to be defined prior to the FV. The OPFOR commander arrived one day and said he would use the system the next day and make a

determination if it would fulfill his requirements. Then, during testing the next day, the criterion was whether or not he could move his units in a prescribed fashion and time through specific phase lines. The result of the test was a recommendation to not use the BBS/SIMNET link in STOW-E (a week before the exercise). Why? Because units had gotten stuck in water (a known limitation), and units had wandered around tree lines (another known limitation), making them late to the phase lines. Some other problems were due to the 75% data loss to the OPFOR tent (which had not yet been discovered) and the new BBS STOW-E database that had obstacles in it that the BBS operators weren't accustomed to maneuvering around. Given a second chance, the data-loss problem was solved, some changes were made to the SAF code, and the system passed all of the imposed criteria.

Major subcomponents need to be tested during the FV. The terrain database changes for both the SAF ctdb and the BBS digital database caused some added stress down the stretch. The BBS operators just did not have enough time to use the new database prior to the exercise.

Configuration needs to be "locked in" during the FV. While the OPFOR tent worked out well, it needed to be in place before FV2 so that the problems described above could have been sorted out before the last week.

The Stealth view was an immense help and would have been very beneficial during the FV. In fact, it would have saved a lot of time and effort if it had been present during lab testing. Its addition to the BBS setup at Hohenfels a week and a half before the exercise provided invaluable debugging information on why vehicles were getting stuck, provided a great visual cue for preparing movement legs for BBS unit movement, and displayed BBS units moving through the terrain during the exercise. The Stealth operator would help the unit prepare its mission by doing a flyover of the proposed BBS movement route, then, during the exercise, would give direction to units that got stuck or had other problems. Many workhours could have been spent more productively if there had been a Stealth at NRaD for testing.

SAF technical expertise should be available for troubleshooting during operational use of the system. In the future, if SAF code is used, technical support should be available to answer operators' questions (e.g., Can the hash table be fixed? Why is it crashing on "travel-on road"? How is water turned off? How do you turn the tree canopies off? Why do the aircraft wander so much?, etc.).

Exercise control needs to be well-coordinated with the exercise commanders. At times there seemed to be some sort of disconnect between exercise control in the SEAF and the exercise going on in Hohenfels. In some instances, operational questions were asked of Hohenfels that should have been directed to the operational side of the house. The SEAF exercise control was on a schedule that didn't seem to always coincide with the schedule in the "box" at BBS. Exercise control should also be practiced during the FV since it did seem to improve each day.

All SEAF/SIMNET personnel should have been required to tour Hohenfels (CMTC-IS and BBS) to get a better perspective of the training exercise as experienced by the soldier.

3.1.13 The BBS STOW-E Transition

The transition of the aggregation/deaggregation technology provided by the BBS/SIMNET interface is likely to begin shortly as a component of the Prairie Warrior '95 exercise. It is expected that there will be a short-term (4 months') transition from BBS 2.3.2 to BBS 3.0, and a mid-term (8 months') transition from current AIU/SAF 4.3.3 capabilities to the AIU/ModSAF 1.2.

The BBS/ModSAF effort is scheduled for its first System Integration Test (SIT) in March 1995. Many problems will be identified, and a report on status and proposed schedule to completion will be

written. The focus of the effort is moving functionality to the AIU, and testing with the complete system. The current problem looming on the horizon is still how to get more entities per SAF engine. Estimates of 30 to 40 vehicles per SAF (ModSAF) engine are still being observed.

3.2 DEFENSE SIMULATION INTERNET

3.2.1 Introduction

The Defense Simulation Internet (DSI) is an Internet Protocol (IP) based network that provides real-time simulation and video teleconferencing, to approximately 100 subscribers worldwide. The DSI uses the Stream Protocol (SP) to accommodate real-time applications and support bandwidth reservation and multicast capability.

As part of the DSI's Phase I Upgrade, the DSI's CONUS backbone is now composed of Wellfleet Concentrator Node (CN) and Link Node (LN) routers. The CN routers are interconnected by a circuit group of four T1s, at nine hub locations on the network backbone. Each T-1 has a bandwidth of approximately 1.5 Mbps minus overhead. The CN hardware supports up to 52 local area and wide area network (LAN/WAN) connections with an aggregate packet forwarding rate of 188,000 packets per second (pps). The LN hardware supports up to 16 LAN/WAN connections with an aggregate packet forwarding rate of 58,000 pps. The Wellfleet routers provide enhanced performance including greater reliability and higher throughput, expanded connectivity for DSI users, and increased bandwidth to meet growing user requirements. The Phase 1 Backbone architecture uses frame relay as the data link protocol and Open Shortest Path First as the routing protocol.

The DSI played a major role in supporting the communications requirements for STOW-E. STOW-E incorporated 13 DSI sites in the CONUS, Germany, and England. The classification of the exercise was a combination of SECRET/NOFORN and US1.

3.2.2 Challenges

To support a seamless battle simulation for STOW-E, DSI required a large bandwidth and robust topology. Various network components were upgraded to increase available bandwidth. In addition, augmenting systems, such as the application gateway, were developed to optimize bandwidth utilization.

Another challenge that faced STOW-E was providing interaction between unclassified and classified sites. To meet this challenge, an exercise configuration using a one-way "Guard" was implemented. This component injected the traffic from the unclassified sub-exercise into the secure sub-exercise. As a result, the sites in the secure sub-exercise received all the traffic in both the secure and unclassified sub-exercises without compromising security.

3.2.3 DSI Network Management and Control

During STOW-E, the DSI network management and control functions were performed from four locations: the Exercise Network Management Center (ENMC) at Arlington, VA; the Network Control Center at the DSI Customer Service Center in Leavenworth, KS; the Bolt, Beraneck, and Newman (BBN) Network Operations Center (NOC) in Cambridge, MA; and the SEAF in Grafenwoehr, Germany. The ENMC was the primary network management and control center during STOW-E.

3.2.4 Supplemental Connectivity

The Defense Simulation Internet was supplemented for simulation data transfer by two subnets. The first subnet was DSI "backdoor" connections. TACCSF at Kirtland AFB had a backdoor

connection to the Pentagon; Lakenheath Air Force Simulators were connected via the Grafenwoehr, Germany, DSI node; the AEGIS Cruiser at Mayport was connected by way of the Navy MUTTS connectivity system from Dam Neck, VA; and Cockpit Simulators at Armstrong Labs in Mesa, AZ, were connected with ACETEF at Patuxent River, MD. The second sub-net included a number of T-1 and E-1 circuits "hardwired" between Grafenwoehr and Hohenfels, Germany, providing that connection with over 5-Mbps bandwidth.

3.2.5 DSI Results and Observations

Leading up to STOW-E, Sub-System Integration Testing, which began in April '94, indicated that the reliability of the DSI was not satisfactory to complete STOW-E. Reliability was measured in terms of hours scheduled versus hours useable by simulations to conduct testing. In the June-July '94 timeframe during STOW-E Sub-System Integration Testing, DSI reliability was approximately 60% to 70%. Two changes were implemented in late summer/early fall that increased the reliability during final testing stages. First, it was decided that the maturity of the DSI Phase 1 was sufficiently robust to merit cut over to Phase 1. Testing prior to that timeframe had been conducted on Phase 0. Phase 1 provided improved commercial off-the-shelf switches (Wellfleet's) and redundancy in circuit routing to the sites. Secondly, it was decided to bring onboard the DSI primary vendor to supplement the DSI operations and maintenance vendor for the conduct of STOW-E. Testing reliability increased dramatically during October '94. For the execution of STOW-E over the period of 4 to 7 November 1994, during operations that ran approximately 16 hours per day, reliability of the DSI was 99%.

Two notes need to supplement this apparently superb network performance. First, the network was manned 24 hours a day at every site by both the DSI "manufacturer" and by the DSI "operations and maintenance" contractor. Second, the network was brought down every night for maintenance and was systematically brought back up. This process took 2 hours nightly. While the success of the DSI was overwhelmingly positive and a key factor in the overall success of STOW-E, it was <u>not</u> a hands-off operation. Extraordinary effort and hands-on care were devoted to the network throughout the STOW-E period of performance, 4 to 7 November 1994.

It should be pointed out that while DSI is equipped to simultaneously handle voice, data, and image, during STOW-E, it primarily handled only data. Tactical and coordination voice circuits where handled by DSN or dial-up lines. There was a video teleconference (VTC) between Grafenwoehr and Hohenfels, but it was over a dedicated T1 vice DSI. An occasional VTC, during non-exercise hours, was conducted over the DSI between Grafenwoehr and IDA in Washington or WISSARD at Norfolk, VA. Over 99% of the traffic on the DSI during STOW-E was DIS Protocol Data Units (PDUs). The average total scenario load between 4 to 7 November 1994 STOW-E operations was approximately 900 to 1300 entities depending on the operation for that day. The peak each day during STOW-E was normally around 1800 fully interactive entities. Scenario load during testing prior STOW-E did reach 3500 entities on one occasion. The DSI was reliable during all of these circumstances.

3.3 SCALEABILITY

3.3.1 Goal

The goal of the Scaleability program is to support the evolution of DIS technology by pushing back the limitations on the number of entities that can participate in an exercise. Since the load on the simulation network grows in proportion to the entity count, the load will always, at some point,

exceed the available bandwidth. To push back this boundary, techniques have been developed to increase the density of information that can be transmitted across a given bandwidth.

3.3.2 Challenge

For STOW-E, approximately 1800 entities were generated at sites around the world. Because of the geometry of the sites on the network, high-traffic segments of the DSI needed to support a traffic load of 4.9 Mbps. The DSI was limited to a throughput of 1.1 Mbps, however, so the offered load to the network had to be reduced by approximately 80%.

Offered Load: 4.9 Mbps
Available Bandwidth: 1.1 Mbps
Required Reduction in B/W Demand: ~80%

3.3.3 Concept

To accomplish the required reduction in bandwidth demand, a means was developed to transparently determine whether generated data was of value to other sites in the exercise. If the data was required by another site, it was passed on to the Wide Area Network (WAN); if not, the WAN never saw this additional and unnecessary load. This decision-making function was housed in a computer on each LAN referred to as an Application Gateway (AG). The AG further reduced the offered load to the WAN by reformatting the data to achieve more efficient transmissions.

3.3.4 Implementation

Each aspect of the Application Gateway's functionality was embodied by a specific Bandwidth-demand Reduction Technique (BRT). Seven BRTs were integrated into the AG and, though independent, worked in concert to maximize the reduction in the offered load to the network. Each BRT is outlined below.

3.3.4.1 PDU Culling. Data is exchanged between simulation hosts via packets called PDU. There are a variety of PDU types, each designed to transmit a particular type of message. The most common PDU type is the Entity State PDU (ESPDU) that relays information about the location and appearance of a simulated entity. PDU Culling discards all non-DIS PDUs and collision traffic PDUs, in particular, as well as ESPDUs that are not within the playbox boundaries. The collision traffic to be excluded is composed of the Collision PDUs in which the Issuing Entity ID Site matches the Colliding Entity ID Site (i.e., local collisions). PDU Culling routes qualifying ESPDUs to the Grid Filtering Algorithm for further processing. All non-ESPDUs are transmitted because of their negligible contribution to the overall load.

3.3.4.2 Grid Filtering. A playbox area for the current exercise is determined upon startup of the AG. The playbox is divided into squares representing grids that can be referenced by row and column. The width of the grid square is determined at startup with a minimum size of 3 km. Each AG broadcasts Grid Subscribe PDUs to indicate Grids of Interest (GOI) based on the union of the Regions of Interest (ROI) of locally generated entities.

A Comprehensive Union (CU) of GOIs is calculated in the Grid Subscription Processor. PDUs that pass the initial PDU Culling analysis as Entity State PDUs are assigned a grid location based on their coordinates. If the grid location is in the Comprehensive Union, the PDU is processed as an ESPDU. If the assigned grid location is not in the CU, the PDU is marked as a Summary Entity (SE) for further processing.

3.3.4.3 Quiescent Entity Determination (QED). QED is responsible for determining if an entity is inactive. All ESPDUs that are received from the Grid Filtering Algorithm are processed by the Quiescent Entity Determination. The QED compares the most recent ESPDU with the last ESPDU saved in a hash table. If there has been no change in the location, orientation, appearance, or articulated parts, the entity is deemed quiescent. Application Gateways generate ESPDUs for quiescent entities locally, eliminating the need to repeatedly broadcast unchanging information over the WAN.

3.3.4.4 Protocol-Independent Compression Algorithm (PICA). The PICA is a differential, lossless, protocol-independent compression technique that can significantly reduce bit transmission rates in DIS applications. PICA is applied only to ESPDUs in the current AGs. These PDUs, upon first receipt, are saved locally as reference PDUs in the AGs. Subsequent changes to an entity's position or appearance are sent over the network in an abbreviated form as changes to the reference-PDU bit pattern only. The resultant savings in bandwidth usage is the difference in size between complete ESPDUs and these smaller, modifying messages sent in their place.

3.3.4.5 Bundling. The AG Bundling algorithm collects PDUs and concatenates them into larger packets that can be transmitted more efficiently. Bundled packets are transmitted when full (operator selectable up to 1000 bytes) or when the operator-selectable time-out period has been reached.

3.3.4.6 Overload Management. The Overload Management algorithm prevents bottlenecks in the traffic flow by dispersing, over time, the transmission of packets from an overloaded site (as opposed to losing them) and, if that action is insufficient, by intelligently discarding packets according to their priority. The Overload Management algorithm determines the maximum number of packets per second that should be allowed for transmission from the AG. All participating AG sites start out with equal bandwidth percentages, but these percentages can be altered after start-up to accommodate changing data flow patterns.

3.3.4.7 LAN Filter. A Local Union (LU) of GOIs is computed by the Grid Filtering function using the radar ranges of the local simulation entities. This LU is used to filter LAN-bound ESPDUs and ESPDUs created from SE PDUs. If the grid coordinates of an ESPDU are in the LU, the ESPDU is transmitted to the LAN. The LAN Filter also eliminates unnecessary ESPDU data from the LAN-bound streams by employing an entity filter (simulators of subsurface entities would not be interested in land vehicles; therefore, land ESPDUs would not be released to their LAN). All non-ESPDU DIS traffic is transmitted to the LAN without being filtered since the potential reduction in traffic does not warrant the processing cost.

3.3.5 AG STOW-E Results

Table 3-1 summarizes initial AG results for STOW-E. (A separate STOW-E data analysis report will address AG performance in greater detail.)

Table 3-1. AG results for STOW-E.

AG Availability		99.6%
Algorithm Reduction Factors:		
	Compression	2:1
	Grid Filtering	1.1:1
	PDU Culling	TBD*
	Quiescent Entity Service	TBD*
	Bundling	2.5:1
	Load Leveling	TBD*
	LAN Filter	N/A**
AG Combined Data Reduction Factor		15:1
* Transparent to user. Awaiting analysis of data. ** User controllable filter for LAN. Did not affect WAN load.		
Percent of DSI Bandwidth used during peak demand with AG on-line (Peak was approximately 1800 entities)		50%

3.3.6 STOW-E Lessons Learned

3.3.6.1 Operational Issues

a. The long-haul network must support file transfers. Developmental software will always need to be updated, and no other means of transfer is fast enough, convenient enough, or cheap enough.

b. All sites should have a secondary Internet connection with a tape-drive-equipped host to allow for non-DSI transfers of software and data (a "data back channel").

c. Back-channel voice communication links need to be provided to permit technical personnel to coordinate support activities off-line. These phones need to be located next to the host so that the point of contact doesn't need to run back and forth between rooms or buildings.

d. Standard Operating Procedures (SOPs) are required for all operations involving hardware and software use at multiple sites to ensure that equipment and applications will be properly configured when the exercise commences.

e. Every site must be manned by at least two dedicated technical support personnel to prevent fatigue and to allow for the management of unforeseen crises.

f. All operators need to be proficient in UNIX. Classes need to be scheduled well in advance to train all personnel on the basics of text editing, navigation through the hierarchy of directories, manipulation of files, use of peripherals (e.g., tape drives), and use of any specialized software for the exercise. These classes must be mandatory. Written tutorials, while useful and highly recommended, are not substitutes for hands-on instruction.

g. Test schedules cannot be extended over so many hours and so many days that personnel become either mentally or physically fatigued. Tired testers make stupid mistakes and can't troubleshoot even simple problems.

h. To prevent unforeseen problems during tests and exercises, sites must be constrained to generate no more than their allotted number of entities. Unexpectedly high data loads, when already operating near network throughput limits, are a dangerous and unnecessary risk.

i. Projects of the magnitude of STOW-E must be given the highest priority at all participating sites. Intermittent participation, resulting from shared allegiance with other projects, changes the testing parameters, can invalidate data, decreases the effectiveness of the training sessions, and increases the workload on all other participants.

j. Sites should not be permitted to allow their corporate LAN to be connected to their test LAN. This situation floods the WAN with unwanted data unless the "promiscuous mode" is turned off on the T/20. The absence of the promiscuous mode prevents network connectivity from being checked with the Ping program and prevents the transfer of software changes via ftp.

3.3.6.2 Field Testing

a. Full-scale, multisite network testing of new software and procedures must be begun far in advance of any major demonstration. There is no substitute for exercising SOPs and new technologies in the environment where they are expected to perform.

b. Behavior of the long-haul network should be fully analyzed and understood prior to the conduct of a major exercise where additional data is to be collected. Without this information, it is nearly impossible to pinpoint the sources of errors and anomalies.

c. It is helpful to run "immediate action drills" to ensure all personnel know what to do in the event of a computer crash or other problem requiring rapid corrective action.

3.3.6.3 Development Environment

a. If complex software is to be developed in modules, all modules must be completed well in advance of the first scheduled test period. Internal software conflicts can bring an otherwise robust system to its knees.

b. The means to measure the effects of new software, both quantitatively and qualitatively, must be made available to the development team. This includes data analysis tools, Stealth systems, and additional personnel to run the tests.

c. If multiple teams are going to contribute to the final software product, periods of testing with all parties at one site are essential.

3.3.6.4 Algorithms

a. All unnecessary processes (e.g., daemons) running on the AG host must be killed before bringing up the AG to avoid conflicts.

b. The AG's built-in debugging menus were very helpful. All future versions should be similarly equipped.

c. Future versions of the AG should have built-in statistics-gathering capability.

d. Reallocation of bandwidth within the Load Leveling algorithm should be automatic to improve responsiveness.

e. The configuration of the AG control panel should be able to be saved to speed up future restarts.

f. Effectiveness of the QED could possibly be improved if the constraints were relaxed. In other words, allow the QED to handle a tank that is standing still even though its turret is rotating in a repetitive manner. (CPU demand must be considered.)

g. Additional bandwidth savings might be realized by extending compression techniques to other than ESPDUs (the remaining 10% of PDUs).

h. Broadcast Grid Filtering must be replaced by Dynamic Grid Subscription/Multicasting as soon as the long-haul network will support it.

i. Algorithms should be kept as simple as possible so that lower cost CPUs can be employed.

j. A "crisis mode" should be built into the AG to handle data spikes. One solution might be to drop every other PDU for a specified period until the data load returns to normal or the algorithms can ramp up to the demand.

k. A graphical user interface (GUI) would allow non-UNIX-proficient operators to control the functions of the AG with less training and with more assurance. This feature might include a graphical status display and a display of performance statistics. (CPU demand must be considered.)

l. In selecting candidate scaling algorithms, they must be analyzed for their effect on simulation validity.

3.3.6.5 Local Area Networks. While the AG provided the means to scale the long-haul network bandwidth to operate within its capacity, it did not address management of the LANs. Legacy systems, tools such as SIMNET at Grafenwoehr, Germany, and Plan View Displays at nearly all sites were not equipped to handle traffic loads on the order of STOW-E. For example, SIMNET crashed when LAN loads exceeded roughly 1000 entities, and Plan View Displays could not keep up with screen refresh demands at these loads. A key lesson learned is that while the AG solved the WAN issue for STOW-E, significant attention must be given to LAN and legacy system capacities for future STOW demonstrations/exercises. A LAN manager or simulator preprocessor should be considered.

3.4 LIVE/RANGE INSTRUMENTATION

The STOW-E program demonstrated critical simulation technologies by integrating live, virtual, and constructive forces into a seamless electronic battlefield. To assist in achieving this capability, live forces from instrumented ranges were integrated via DIS during STOW-E.

Live systems encounter different challenges than virtual and constructive systems. Some of the challenges particular to live systems include occasional position inaccuracy and loss of connectivity, limited bandwidth between the range and central instrumentation system, data latency, exercise control limitations, differences in exercise topology between live, constructive, and virtual systems, environmental effects, and data completeness.

In order to provide the live element of STOW-E, the CMTC-IS, the TACTS, and USS *Hue City* were integrated to the DIS network.

3.4.1 CMTC

3.4.1.1 Introduction. The CMTC-IS, located in Hohenfels, Germany, was designed and developed to support, through analysis and feedback, U.S. Army, Europe (USAEUR), combined arms training. The instrumented CMTC monitors and controls maneuver training, produces after-action reviews (AARs), standardizes evaluation of training performance, and provides detailed training feedback.

For CMTC-IS to participate in STOW-E, an interface was designed and developed to provide a gateway to the DIS network and thus a link to other simulations.

During STOW-E, the CMTC-IS BODAS provided the CMTC-IS-to-DIS interface, the DIS-to-brigade operations interface, the brigade-level display capability, and the brigade-level AAR.

The entity state data for each instrumented player at CMTC-IS is obtained via the Global Positioning System (GPS) portion of the Simulated Area Weapons Effects/Multiple Integrated Laser Engagement System II (SAWE/MILES) system. This data is then sent to the BODAS Compute Server where it is converted into DIS PDUs and then transmitted to the DIS network. DIS PDUs coming from the DIS network are received by the BODAS Compute Server and processed for display and subsequent AAR generation. The BODAS workstations provide dynamic and static situation displays, control measures, status displays, statistical displays, time tagging of events, AAR preparation, reports, alerts, and audio cuts recorded during the exercise. BODAS workstations, which are implemented on SGI Indy platforms, are also located at the Training Analysis Feedback Facilities (TAFs) of CMTC, and the SIMNET and BBS battalion command stations to ensure a full brigade-level AAR is provided.

3.4.1.2 STOW-E Accomplishments. The CMTC in Hohenfels, Germany, was the first Army Combat Training Center to participate in a large-scale DIS exercise. DIS PDUs, representing live units in the Hohenfels Training Area, were transmitted to the DIS network for interaction and display with other systems in Germany and the CMTC-IS provided another technology first by offering the proof of concept for a state-of-the-art BODAS that provided the brigade-level AAR during STOW-E. The combination of these two technologies and the integration of other DIS systems allowed the brigade commander at CMTC-IS to experience a seamless brigade-level battle. CMTC-IS STOW-E accomplishments can be further described as follows.

3.4.1.2.1 CMTC-IS-to-DIS Interface (transmit). Entity state information was sent for each defined CMTC-IS entity with an update period of every 5 seconds for each entity. The output was selectable as on/off without effecting the BODAS display of any of the other domains. Entity elevation data was obtained from a simulation database instead of using the elevation data received from GPS. This was done to allow the CMTC-IS entities to appear correctly on other systems, including 3-D visual displays, using the same simulation databases. Both direct and indirect fire and detonation events were sent from CMTC-IS to DIS as they occurred.

3.4.1.2.2 DIS-to-BODAS Interface (receive). DIS PDUs were received, converted to CMTC data format, and mixed with the data extracted from CMTC-IS. The processed data included entity state data, aggregate data, and engagement data for both direct and indirect fire events. From this data, the brigade-level picture was built and broadcast to all BODAS workstations for display and AAR preparation.

3.4.1.2.3 Brigade Exercise Control, Monitoring and AAR. BODAS logged data for the CMTC-IS, BBS, SIMNET, and Aviation Test Bed (AVTB) domains and provided a brigade-level AAR. Several issues need to be resolved before BODAS is a deliverable system, but the proof-of-concept was implemented and demonstrated. The BODAS system was capable of brigade-level AAR generation and presentation and included:

a. A view of the brigade sector. This included a display of data received from the DIS WAN with the primary focus on data from BBS, SIMNET, AIRNET, and CMTC. Displays could be set up at the desired level, i.e., brigade, battalion, etc. Specific displays were: (1) situation display, (2) status display, (3) statistical display, and (4) alert display. Displayed information included element location and status, as well as direct and indirect fire events from all domains. Capacities were increased with up to 3500 entities being supported. The entity count is a cumulative count and is divided as follows: 1000 for CMTC-IS players, 2500 for non-CMTC-IS players. Up to 750 units, 2000 indirect fire targets, and 500 scheduled fire missions are supported. Note: The limit of 2500 CMTC-IS was quickly exceeded during the

6 November 1994 BLUE ATTACK mission and the 7 November 1994 MOVEMENT TO CONTACT/COUNTER ATTACK.

b. Generation of control measures. The analysts could build new control measures on the BODAS workstation or display those built in the IS system for tactical force AAR.

c. Creation of AAR outline: This included data from the simulated, constructive, and the live domains and also dynamic and static digital replays. Replays of the mixed domain brigade-level data were available anytime throughout the battle. The BODAS replay data was stored in a highly compressed format (during FV3, BODAS replay data was at roughly 20 times smaller than DIS log data, and the BODAS replay data includes the deaggregated BBS units).

3.4.1.3 Software Development Issues. Several software development issues affected but did not prevent successful CMTC-IS integration.

3.4.1.3.1 CMTC-IS-to-DIS Interface (transmit). For BODAS to process an entity count of 3500 entities, limitations were made on the processing of data in order to save CPU usage. The impact was that anomalies were noted in the representation of CMTC-IS entities on 3-D displays.

Elevation. A file containing a matrix of 25-m spacing altitude values, obtained from S1000 library calls was used. When altitude was desired, the four surrounding altitude points were retrieved from memory, and a bilinear interpolation was performed. This method has two known sources of inaccuracy. The first is in the use of 4 points for interpolation in the square versus 3 points for interpolation in a triangle. The second is the use of 25-m spacing with micro-terrain accounted for at only those points (and not in-between). The result of these two inaccuracies was that the elevation of an entity was observed to be either under or floating over terrain features. To get more accurate elevation data, a canned terrain database (TDB) library call, such as libctdb or S1000, can by used for runtime retrieval. For example, libctdb uses 3 points for interpolation in a triangle with 125-m spacing with micro-terrain between points.

Horizontal Positioning. CMTC-IS entities were occasionally observed to jump between points. Positioning data is received via GPS. Positions from CMTC-IS were reported at a mean 10-m error. Best resolution was at 3 meters with a worst-case error of approximately 30 to 40 meters. During pre-STOW-E testing, the horizontal positions of outgoing CMTC-IS entities were verified to be completely accurate in accordance with their GPS reported locations. Therefore, errors in positioning can be attributed to errors in the GPS fix. No solution has been proposed for the GPS error.

Velocity. Velocity was obtained from instrumented velocity of vehicles. However, velocity is only received some of the time. BODAS generated DIS PDUs with a "no dead-reckoning algorithm" marker. In order for BODAS to dead reckon outgoing entities, velocity will need to be derived from previous updates.

Orientation. Discrete values were coded for each 10 degrees of heading. However, CMTC-IS entities were observed to "crab." This problem has been investigated, but a fix was not implemented during STOW-E since adding the fix would require bringing the system down, which would affect data collection for the AAR.

Fires and Detonations. Both Direct and Indirect Fire and Detonation Events were sent as they were received from CMTC-IS. However, fire events are often received without being tied to detonation events and vice versa. The difficulty becomes pairing a fire event with a detonation. Another issue is extracting the exact number of rounds fired in CMTC-IS. Currently, a predetermined number of rounds for each mission, spread out between the artillery players in the firing unit, is sent.

No target or mission lists are generated. Because of the difficulty in differentiating between direct and indirect fire, accurate target or mission data cannot be built.

Unknown entity types. Due to the wide range of entity types participating in the CMTC-IS exercise, some "Beach Balls" (geodesic shapes to represent unknown entity types) were observed on the 3-D displays. In most cases, this was a result of the 3-D display not having the appropriate model for the entity received. However, it was noted that there were uninstrumented players (i.e., fire markers, observer/controllers) who were injected into CMTC-IS by TAF analysts. BODAS misinterpreted these entities as valid DIS entities and mislabeled them as unknown entity types. Several unsuccessful attempts were made to resolve this intermittent problem prior to and during STOW-E. A decision was made to live with this problem due to risk to other functionality in BODAS. This problem will continue to be investigated.

3.4.1.3.2 DIS-to-BODAS Interface (receive). The entity identification included in the BBS aggregate PDU was different from the entity identification in the entity state PDU when deaggregated. Simply, the same vehicle would be assigned another, completely unrelated ID each time the BBS unit was aggregated or deaggregated. The impact was that slots were being used each time a new ID was received and the 3500 entity limit was reached well before 3500 actual entities were on the battlefield. Although an attempt was made to patch the problem on the receiving end (BODAS), future development should be centered on increasing BODAS' ability to increase or reallocate unused entity slots. Also, the aggregate PDU only incorporates a maximum of 20 entities per AGG PDU. In the case where there are greater than 30 entities in an aggregated unit, true combat strength is reflected incorrectly. This issue requires further analysis.

3.4.1.3.3 Brigade Exercise Control, Monitoring, and AAR. The BODAS workstation windows include the border controls (quit, lower, raise, etc.). The new operating system from SGI has changes in this area. This problem has been investigated, but the fix could not be implemented prior to the STOW-E software freeze.

The BODAS workstation has a small difference in map scale. This is apparent when placing the plastic control measure overlay on the screen for tracing. This is a minor inconvenience for the analyst. This problem has been investigated, but the fix was not implemented prior to the STOW-E software freeze.

There are some capabilities of the BODAS that were inherited from the CMTC-IS and that were not tested. These are not mainstream features (archiving and recovery of exercise data [currently done manually], weather status, all alert filters, etc.) and did not affect STOW-E.

The new version of Informix (the COTS relational database utility) is not compatible with the baseline CMTC code. Informix no longer sells the exact product used for CMTC. This will require additional effort to convert source code to be used by the new product.

In order to time tag audio at the BODAS workstation, a link between the BODAS workstation and the CMTC-IS VCS is required. This task has not been completed although a work-around exists for the audio time tags to be entered on a CMTC-IS station and replayed manually in the BODAS AAR (the user included approximately 3 audio cuts in brigade AARs this year).

3.4.1.4 Future Efforts. Providing the user with a turn-key BODAS system should be the primary future effort. The brigade upgrade is the preferred next step because it takes advantage of the work and the lessons learned on STOW-E. STOW-E consisted of the tangible items such as software and hardware but also the knowledge gained by the many individuals who made STOW-E work. In addition to the brigade upgrade, the following should be considered.

a. Integration of the 3-D display into the AAR. The use of a "Stealth" 3-D display during STOW-E was manually synchronized with the instrumented AAR. This was difficult and required additional operators. Automating the 3-D interface with the AAR, including 3-D replay as a step in the AAR, should be investigated.

b. Automatic definition of players and units for BBS and CMTC-IS. This would use the DIS interface to transfer the task force unit organization definition as the unit moves from one training domain to the other. Currently, analysts type this information in at both BBS and CMTC-IS for the same unit. With an electronic link, this information could be shared and time and effort could be saved.

c. Automatic flag element change when an assigned flag element receives a kill. When monitoring a complete brigade, it will be difficult for the analysts to manually change the flag element when killed (the flag element is used to position the unit symbol on the map).

d. Unit attrition symbology should be added to show units with 35% combat loss. A black slash could be used similar to a dead-vehicle symbol. This would greatly improve the display of the brigade picture.

e. A function key (hot button) for stepping through the AAR step is desired. If the brigade upgrade is not immediately contracted, we recommend developing the BODAS system into a turn-key product. The BODAS system was built with the understanding this was a proof of concept demonstration, and it is not quite ready as a product. This would require a small effort after STOW-E. Additional requirements related to this may be the use of video in the BODAS AAR.

3.4.2 Tactical Aircrew Combat Training System (TACTS)

3.4.2.1 Introduction. The Tactical Aircrew Combat Training System (TACTS) ranges are advanced training systems designed to provide an effective means to improve aircrew proficiency in air-to-air, air-to-surface combat, and electronic warfare (EW) mission areas. During a training mission, data containing information on the aircraft's maneuvers, employment of weapon systems, operation of radio frequency and computer-simulated ground threats, and the employment of aircraft countermeasures are collected, recorded, and displayed for monitoring and control. The recorded data is used during debrief sessions so that the aircrew may recognize weapon envelope boundaries, observe the results of simulated missile and gun employment, and simulate deliveries against realistic surface targets/threat emitters.

The primary goal in STOW-E was to provide an interface unit to allow the ability of aircraft positional data and weapon release signals provided by the TACTS range to be transformed to the DIS protocol to provide interaction with other virtual simulation systems. This function was performed in the AIU_g, which is currently on an SGI Indigo2 Extreme platform. Development is ongoing to provide two-way interaction by allowing a remote participant to control the threat emitters located on the range. This capability will allow EW-capable aircraft to participate in the training opportunities that are currently available only to the fighter and attack communities.

3.4.2.2 System Overview. Connectivity of live aircraft with the DSI was accomplished via the TACTS/Air Combat Maneuvering Instrumentation (TACTS/ACMI) air/ground radio frequency (R/F) data link. The TACTS/ACMI system consists of four subsystems. The Aircraft Instrumentation Subsystem (AIS), carried by each participating aircraft, interfaces with the aircraft and provides digital and range data to the rest of the system via the Tracking Instrumentation Subsystem (TIS). The TIS includes numerous remote stations and one or two master stations that together gather data from each

AIS and relay the information to the Control and Computation Subsystem (CCS). The TIS also accepts update data from the CCS for transmission to the AIS via the TIS remote stations.

The principal objective of including live aircraft in a seamless simulation is to define, solve, and demonstrate the interfacing functionality of a distributed interactive warfighting environment composed of real, dynamic, high-performance objects (tactical aircraft) and simulated objects (aircraft, missiles, etc.) in a common real/simulated environment.

The TACTS/ACMI integration effort required the development of the AIU_gs to provide the interfacing function between the DSI and the TACTS range. The AIU_gs is the gateway between the TACTS/ACMI system and the ground-based simulation network. The AIU_gs was implemented on an SGI workstation and has the following major functions:

a. Manages the communication interface with the DIS network, provides entity dead reckoning, entity filtering, and user interface.

b. Manages the communication interface with the CCS, processes DIS PDUs, and processes CCS data messages.

c. Manages the communication interface with the Highly Dynamic (HyDy) Display and Debriefing Subsystem (HDDS), processes DIS PDUs, and builds HDDS display messages.

The AIU_gs has three external hardware interfaces that use the DIS network interface, the CCS interface, and an HDDS interface.

The HDDS was a display system for air entities both on the network and operating on the TACTS range. Developed under the HyDy program, its major function was to provide a wide area view of the air battle and air-to-ground targeting interactions.

3.4.2.3 Control and Computation Subsystem (CCS) Modifications

3.4.2.3.1 Aircraft Entities. Modifications to the CCS source code to accept inputs from the AIU_gs were implemented. This provided for the capability of up- and down-linking aircraft from and to the DSI. Testing the capability of placing an aircraft entity onto the DSI from the TACTS subsystem was limited by the available number of live aircraft available. At most, there were two live aircraft available for this purpose. Both entities were successfully placed on the network. With the use of mission recordings (a playback feature of the CCS), this number was increased to three aircraft. The full capability of TACTS, 36 live aircraft, could not be tested due to the bandwidth restrictions of the DSI with this level of network traffic.

With the AIU_gs-to-CCS uplink, problems were noted when large numbers of aircraft were coming from the network. When the system was tested with 33 DSI aircraft and 2 threats, the CCS failed to maintain updated files on approximately half of them, and even then, the updating was not consistent. When the input was throttled down to 15 DIS aircraft, the CCS began updating all entities on a normal basis. No reason for this has been determined.

3.4.2.3.2 Detonation PDUs. Since the TACTS system scores bomb drops and determines the "probability of kill" under its own simulation process, this result must, in turn, be translated into DIS. This mapping was verified to be operational. Also, since the TACTS system will indicate conditions where a target was partially disabled, the AIU_gs was able to produce a detonation PDU when the accumulated "probability of kill" reached a specified level.

3.4.2.3.3 Conversion from Virtual to Live Entities. The conversion from a virtual entity (WISSARD lab) to a live aircraft (Cherry Point) was tested. Due to the lack of a method to go between

these two types of entities, this function could not be performed via the network. Thus in this area, all efforts to turn on and off the respective entity were coordinated by the operators over the voice network.

3.4.2.3.4 Uplink to Aircraft From DSI. The capability for this to take place was implemented but not tested due to the requirement for the aircraft on the TACTS range to be loaded with an ALR-67 pod. If this could have taken place, the TACTS system would have been able to stimulate the threat warning indicators in the aircraft from other surface-to-air missile (SAM) sites on the network. This path of communication has been tested in the lab, but not under a live situation. Data reduction of the CCS mission recording tapes is planned to be conducted at a later date to determine if the information was present to drive the threat warning indicators.

3.4.2.3.5 Interaction Between A/C Pilot and Network Controllers. Via the V4 communications network, a live F/A-18 (Cherry Point) was able to be controlled by an E-2C controller (Pax River) providing a realistic situation. The controller was able to see the F/A-18 on his tactical displays and vector the pilot in for a laser-guided bomb drop against a hostile target.

3.4.2.3.6 HDDS Subsystem. Beyond the development of HDDS for the HyDy Project, HDDS was modified to provide support for the Stealth PDU and displays for SAM-site type emitters that emanate from ships and submarines. Both of these were successfully implemented, but the HDDS will not display the actual ground-based emitter.

Since the HDDS displays an area of 200 by 150 nm, and each Stealth PDU is set to filter in 66.7- by 75-nm boxes, the HDDS had to transmit multiple requests to the AG so that it would receive all data on the entities in its area of interest. The HDDS transmitted six requests that were successfully processed in the AG and enabled the entity traffic in the area of interest to be passed.

3.4.2.4 Lessons Learned. For any exercise requiring live fleet support, it is imperative to ascertain fleet assets early in the process. There were certain capabilities that required the live aircraft asset to be outfitted with specific equipment that would enable the testing of all of the capabilities implemented in the system.

3.4.3 USS *Hue City* (CG 66)

3.4.3.1 Objectives. The stated primary objective of the Navy was to demonstrate the potential to train personnel at all levels, from individual tactical console operators up through the Battle Group Commander, in a DIS environment. Additional goals included exposing the Fleet to DIS simulation potential, accelerating development of the Battle Force Tactical Trainer (BFTT), and bench marking Navy DIS technology for use in future DIS applications. Toward this end, an active fleet AEGIS cruiser, USS *Hue City* (CG 66), was a participant in STOW-E.

3.4.3.2 Background. *Hue City* was moored at Naval Station Mayport, Florida, during STOW-E. Even though STOW-E was a technical demonstration and not a training evolution for the Navy, all tactical consoles and voice circuits were manned by fleet personnel.

3.4.3.3 DSI Connectivity. The DSI network connection to *Hue City* passed from the DSI node at Tactical Training Group Atlantic (TACTRAGRULANT), over a 1-mile-long, fiber-optic line to the BFTT shore site, at Fleet Combat Training Center Atlantic (FCTCLANT), Dam Neck, Virginia. From there, a T-1 line went to the Multi-Unit Tactical Training System (MUTTS) tower at Mayport, Florida. Pierside connection to *Hue City* was through a wireless LAN. This effectively constituted a separate, secure, tail circuit from the DSI network.

3.4.3.4 Technical. BFTT is a closed-loop, interactive simulation, tactical combat training system. It provides scenario generation and control, simulation of friendly and enemy forces, and stimulation of organic shipboard sensors, data acquisition, reconstruction, and operator performance feedback, as well as connectivity with external scenario control and communication with remote sites through MUTTS. MUTTS integrates tactical communications capability (eight live voice circuits), a Link 11 circuit (not used for STOW-E), and a data line for network traffic with 500-KB bandwidth. Standard Navy TAC-III consoles onboard *Hue City* were used to display all tracks. Exercise Control and tactical voice communications with other STOW-E sites were maintained over six cellular telephones connected through Defense Switched Network (DSN) and Federal Telephone System (FTS).

3.4.3.5 Results. Significant interface problems with *Hue City* during the first 2 days of STOW-E severely hampered examining a complete DIS environment at the Battle Group Commander level. Incoming DIS simulation data was not consistent, producing intermittent tracks. Software quick fixes employed during STOW-E improved data consistency, but did not totally resolve the problem. The BFTT Program Office is investigating the source of the problem to determine a solution. A network limitation of 300-KB bandwidth was experienced at FCTCLANT. BFTT performance began to degrade when it handled more than 100 entities. Significant benefits from participation included the revelation of some BFTT shortcomings, both design and performance, that will help the BFTT Program Office to make corrections and enhance flexibility. The BFTT Program Manager estimates an 18-month savings in development time as a result of exposing the BFTT prototype to joint simulation in its early stages. The Navy's primary objective of demonstrating the potential to train personnel at all levels, from individual tactical console operators up through the Battle Group Commander, in a DIS environment, was met.

3.5 TERRAIN DATABASE

3.5.1 Background

Since 1990, the U.S. Army Topographic Engineering Center (TEC) has developed more than 10 tailored terrain databases for simulation networking in support of ARPA and various Army customers. This section describes the family of terrain database products developed to support the heterogeneous DIS system that link live, virtual, and constructive simulations in STOW-E.

3.5.2 Objectives

The objectives of the ARPA Synthetics Environments Program include development of advanced technology to represent and generate digital terrain databases (TDBs) to support increasingly large and complex STOW exercises.

3.5.3 Approach

Mapping, reconnaissance, and Earth resources imagery are used to assess, update, and enhance standard digital map data from the Defense Mapping Agency (DMA) to generate and maintain a digital model of the geographic area of interest. Simulation-specific software modules are developed to transform the common digital geographic model into a set of tailored real-time TDBs and associated map products.

3.5.4 Synthetic Environment (SE) Products

The STOW-E synthetic environments consist of a family of interoperable, TDB products that support distributed ground, air, and naval simulations linked via DIS protocols on the DSI.

3.5.4.1 Ground Operations TDB. The Ground Operations TDB is the highest resolution TDB containing transportation, vegetation, drainage, soils, building, and other key complex features of the terrain surface. The database was generated from 1 arc-second (approximately 30 meters) DMA Digital Terrain Elevation Data (DTED) and DMA Interim Terrain Data (ITD) (derived from the 1:50,000 scale operational terrain analysis overlays). Imagery, map, and field data were used to populate additional natural and cultural features. The Ground Operations TDB covers a geographic area 64 km by 84 km that includes Grafenwoehr and Hohenfels, Germany. The data was furnished to STOW-E participants in a variety of formats: SIMNET visual, PVD, SAF, and Management Command and Control (MCC) console formats; "Flight" format for visual simulation; and rasterized feature files for the BBS. In addition, Simulation Maps (SIMMaps) of the STOW-E ground operations area were produced in the style of DMA Topographical Line Maps based on the contents of simulation TDB.

3.5.4.2 Air Operations TDB. The Air Operations TDB covers a geographic area of 232 km by 232 km in northern Bavaria that includes the Ground Operations TDB area. This is a multiresolution database with high-resolution features replicated from the Ground Operations TDB and a lower resolution textured terrain surface outside the ground operations area. The database was generated primarily from 3 arc-second (approximately 100 meters) DTED thinned to a 500-meter grid. Natural and cultural features were derived from the ground operations database. The data was delivered in a variety of formats including versions compiled for SIMNET visual simulators, PVD, SAF, "Flight," and Loral Advanced Distributed Simulation (LADS) "Vistaworks." Additional standard data sources (e.g., Digital Feature Analysis Data (DFAD)) were provided to STOW-E participants to support construction of tailored flight databases.

3.5.4.3 Naval Operations TDB. The Naval Operations TDB covers a geographical area 244 km by 244 km centered in the northern Mediterranean Sea. The database was generated from 3 arc-second (approximately 100 meters) DTED thinned to a 500-meter grid. Coastline features were extracted and thinned from the DMA Digital Chart of the World. The data was delivered in a variety of formats including versions compiled for SIMNET visual simulators, PVD, SAF, "Flight," and LADS "Vistaworks." Other standard data sources (e.g., DFAD) were provided to STOW-E participants to support construction of additional databases.

3.5.5 TDB Generation Process

The TDB generation process consists of several phases: design, source collection, data preprocessing and setup, terrain surface generation, editing, preliminary testing, SIMMaps production, compilation, testing, and distribution.

3.5.5.1 Design. The database design process starts with the gathering of user requirements for data content, schedule, and deliverables. The STOW-E areas of operation were plotted on maps to identify required sources and to estimate design parameters for the project. Preliminary decisions were made based on expected data sources and available equipment and software tools. A novel approach to generating Triangular Irregular Network (TIN) was selected to provide enhanced fidelity to the terrain surface. The project schedule provided for incremental deliveries required for STOW-E Functional Validation tests.

3.5.5.2 Source Data Collection. Maps and digital terrain data of the STOW-E area were gathered and evaluated. Sources that met the fidelity requirements of the project were selected for use in database construction. Data modeling personnel traveled to the STOW-E area to collect ground photographs and videotape to improve understanding of the terrain and to support subsequent database validation.

3.5.5.3 Data Pre-Processing and Database Setup. Digital data sources in ITD Standard Linear Format (SLF) were read and thinned using a commercial Geographic Information System (GIS). Thinning reduced the volume of data to the level acceptable for distributed simulation. Data attributes were mapped from the detailed DMA source codes to the limited attribution required for the simulation systems. Files that identify the project area were initialized and site-specific models were defined.

3.5.5.4 Terrain Surface Generation. The integrated Triangular Irregular Networks (iTIN) method developed by the Carnegie–Mellon University was used to generate the terrain surface for the Ground Operations TDB. This automated method iteratively builds a surface consisting of polygons (mostly triangles) that take into consideration the location of significant terrain features (e.g., transportation and drainage). The method also controls the allowable number of polygons to meet the constraints of the target simulators.

3.5.5.5 Database Editing. SIMNET S1000 database modeling tools were used in the TDB generation phase. The terrain surface was edited to correct key terrain features that were distorted by the automated iTIN process. The transportation and drainage network was adjusted to be consistent with the terrain surface. Features extracted from stereo imagery with the Digital Photogrammetric Workstation were used to augment the database as needed. In addition, feature models (e.g., buildings) were placed in their proper location; vegetation features were added; and soil types were specified.

3.5.5.6 TDB Preliminary Testing. Preliminary testing was conducted as part of the TDB generation process. The database was compiled into a run-time format for the visual simulators available at TEC. Error detection tools of the TDB generation software were used to identify problem locations. In addition, the tester flew over the TDB inspecting the database visually logging discrepancies with known information (e.g., imagery, maps, field data). Reported errors were analyzed and corrected. The process was iterated until no more errors were reported by the software tools or observed by the tester and the database was considered "frozen."

3.5.5.7 SIMMaps Production. Twelve 1:50,000 scale SIMMaps were produced for the ground operations area. The terrain and feature data from the "frozen" database were imported into a commercial GIS where automated cartographic tools were used to symbolize all the map features. The SIMMaps were designed to emulate DMA Topographic Line Maps. After examination of color proof plots by cartographers, film color separates were generated with a large format printer and paper maps were generated in volume by lithographic press.

3.5.5.8 Brigade/Battalion Battle Simulation (BBS). Terrain features required for BBS TDB generation were extracted from the "frozen" database through GIS vector-to-raster operations and furnished to the National Simulation Center (NSC) for incorporation into the real-time BBS TDB.

3.5.5.9 Database Compilation. Automated TDB compilers were used to generate the various formats required by STOW-E simulation systems. Each of the compilation activities resulted in a database in one of the following formats: SIMNET or Flight visual simulation, SAF, PVD, MCC, or BBS raster files.

3.5.5.10 Testing. Final product testing occurred after compilation by loading the visual and SAF databases on the appropriate systems at TEC and at the Institute for Defense Analysis (IDA). Visual databases were tested primarily by "flying" over the database extent. For SAF databases, vehicle behavior was checked against known behavior. Anomalies observed in this phase of testing were addressed by corrections to the TDB source and recompilation.

3.5.5.11 Distribution. The STOW-E TDBs were installed on a file server at IDA for distribution to STOW-E participants via Internet. The TDBs were also shipped to selected participants in request magnetic media formats. Sheets of paper SIMMaps were sent to all STOW-E participants.

3.5.6 Technology and Tools for TDB Construction

A variety of general purpose and specialized tools were used to generate the STOW-E TDBs. The S1000 modeling and TDB construction tools that were developed to support the ARPA SIMNET Program continue to evolve; for example, a new S1000 Application Programmer's Interface facilitates direct access to the source data. The Arc/Info GIS was used throughout the TDB generation process to input, process, edit, and perform cartographic symbolization. Features in the standard data sources (ITS) were assessed and augmented with a variety of stereo imagery using the Digital Photogrammetric Workstation. Automated generation of iTIN surfaces for distributed simulation represents on-going research at the Digital Mapping Laboratory, Carnegie-Mellon University, under the joint sponsorship of ARPA and TEC. The STOW-E ground operations TDB represents the first time that this technology has been applied to a project of this extent and complexity.

3.6 MODULAR SEMI-AUTOMATED FORCES

The What If Simulation System for Advanced Research and Development (WISSARD) is located at the Naval Air Station Oceana, Virginia Beach, Virginia. This section focuses on how WISSARD employed Modular Semi-Automated Forces (ModSAF) in support of STOW-E, WISSARD STOW-E operations in general, and some high-level discussion of ModSAF operation. WISSARD provided not only ModSAF to the STOW-E demonstration but also Intelligent Forces (IFOR), F-14 simulators, and an F-18 simulator. Section 3.7 of this document describes IFOR and its participation in STOW-E. There are references to IFOR in this section but it is from an operational viewpoint. There is a brief description of the F-14 and F-18 simulator participation as well. Note that all STOW-E scenario events are referenced from the Navy tactical scenario developed specifically for the STOW-E demonstration by members of the staff of Commander, Tactical Training Group Atlantic.

3.6.1 WISSARD Computer-Generated Forces Workstation Configuration

WISSARD output computer-generated forces (ModSAF and IFOR) from a total of six SGI workstations. Four workstations were dedicated for ModSAF generation. Two workstations were dedicated for IFOR generation. A seventh workstation was used as a "pocket" SAF system. This workstation was used by "Navy" (the U.S. Navy exercise liaison officer) as a Battlemaster-like station for observation, not to generate entities. WISSARD used ModSAF Version 1.3 and STOW-E TDB –0104 for its ModSAF workstations.

WISSARD generated ModSAF aircraft from four workstations. One workstation, an SGI Iris Indigo (R4000) provided BLUFOR and was set up to function as a SAF Station. This workstation was paired up with an SGI Indigo Extreme (R4400) that functioned as a SAF Simulator (SAF Sim) for the machine. Another SGI Iris Indigo (R4000) was used to provide Opposition Forces (OPFOR) and was set up to function as a SAF Station. This R4000 was paired with another R4000 that functioned as a SAF Sim for the OPFOR machine. Experience in generating vehicles during the period leading up to STOW-E led to the decision to pair up discrete machines for use as SAF Stations and SAF Sims.

WISSARD generated IFOR from two workstations. An SGI Indy (R4400) was used to generate IFOR vehicles in conjunction with another SGI Indigo Extreme (R4400).

One SGI Indigo Extreme (R4400) was used as a "pocket" SAF for the person manning the WISSARD Exercise Coordinator station. This machine was not used to generate any entities during the 4-day STOW-E demonstration period but was used for observation.

3.6.2 Persistent Object Protocol Database ID Numbers

For STOW-E, WISSARD paired workstations to function as SAF Stations and SAF Sims through the use of discrete Persistent Object Protocol (POP) database ID numbers. Additionally, any other ModSAF workstation on the WISSARD LAN was given its own discrete POP database ID number to preclude unwanted intrusion from ModSAF systems at other sites.

The implementation of discrete POP database numbers and SAF Station and SAF Sim pairings gave WISSARD two major options: (1) For example, if one pairing of machines for OPFOR had a problem necessitating a reboot, it would only affect the operations from that set of machines, not the operation of entities from another pairing of machines supporting BLUFOR. (2) Management of workstations in this fashion allowed management of the ModSAF loading. Knowing the load the workstations could handle before crashing, WISSARD could "flow" the entities throughout the scenario in an orderly fashion. If machines from other sites were to use WISSARD workstation excess capacity, it would become difficult to manage the creation of new entities when dictated by the scenario. Discrete POP database ID numbers made WISSARD ModSAF network operations more manageable and predictable.

3.6.3 Scheduled WISSARD ModSAF and IFOR Entities for STOW-E

ModSAF and IFOR Force Mix entities included the following types: F/A-18, F-14, MiG-29, KS-3 (vehicle approximated by an A-10), and AWACS. WISSARD attempted to remain within the bounds of the preplanned entity count due to sizing of the Application Gateway and network load planning. Deviations from the plan were made with the approval of the STOW-E Navy representative located on-site at WISSARD. The maximum number of computer-generated vehicles was achieved on 6 November:

Day 3, time 0+00 to 2+00: 29 ModSAF/0 IFOR
Day 3, time 2+00 to 4+00: 19 ModSAF/7 IFOR (IFOR: MiG-29)
Day 3, time 4+00 to 6+00: 25 ModSAF/2 IFOR (IFOR: MiG-29)
Day 3 Totals: 73 ModSAF/9 IFOR for 82 computer-generated vehicles

3.6.3.1 Additional WISSARD-Generated Entities for STOW-E. The following three simulators were planned to participate in STOW-E:

a. WISSARD F-14 Simulators: These are Navy Training Device 2E6, F-14A Air Combat Maneuvering (ACM) Trainers. Composed of two trainers, each is a 40-foot dome procedural trainer used to teach the basics of air-combat-maneuvering. They can operate in either the integrated mode where both trainers are brought up together and work in unison or the independent mode where each dome trainer operates independent of the other with no merging of operations.

b. WISSARD F/A-18 Simulator: This is a workstation-based F/A-18 Hands on Throttle and Stick (HOTAS) simulator optimized for beyond-visual-range air-to-air engagements. This Basic Air Tactics Trainer (BATT) is a VAX-based rack mount arrangement of cathode-ray tubes (CRTs) coupled with a shelf holding replicas of the F/A-18 throttle and stick. CRT graphics are driven by two SGI 4D/310VGXT computers. The BATT was configured with

two touch-sensitive CRTs. The upper CRT displayed an out-the-window view with the HUD image superimposed. The lower CRT displayed three multi-function displays and various other essential-to-flight indicators. The BATT operates on an NAS Fallon, NV, terrain database. Through the use of coordinate transformation, it participated in the STOW-E theater of operations.

c. Fixed Wing Air-to-Ground Simulator: WISSARD had planned to have two air-to-ground simulators. Due to technical problems integrating them onto the DIS network and a very late start, they were not used for STOW-E. They were to have flown during one event per day for a strike into the TDB.

3.6.4 Highlights of WISSARD Manned Simulator Operation for STOW-E

The following are accomplishments during STOW-E:

a. First formation flight with actual aircraft, manned simulators, and computer-generated forces.

b. Communication link with "Hawkeye" Cherry Point TACTS Range Control and with live aircraft.

c. Formation flight/coordinated strike with F-16 trainer (Falcon Star) in Grafenwoehr, Germany, with air control provided by the TACCSF AWACS. The visual displays in the domes were as solid as for ModSAF/IFOR workstation displays, and formation flight was maintained for the 160-nm strike route.

d. Formation flight/coordinated strike (300-nm route) with the Pax River F-18 manned simulator, the WISSARD F-18 BATT, the TACCSF computer-generated F-15s, and all under TACCSF AWACS control.

e. Formation flight on Armstrong Lab's F-16 simulators over the TDB.

3.6.5 Lessons Learned, Comments, and Recommendations

Given the stage of the development of the air model for ModSAF and the relative lack of attention it has received over years of ground maneuver SIMNET SAFOR and ground maneuver ModSAF development, ModSAF Air effectively provides the combat domain with a large number of air entities possessing basic offensive and defensive capabilities. ModSAF Air proved to be good for basic targeting and to elicit initial behaviors from flight crews. It is recommended that work continue on the ModSAF Air vehicles to mature their characteristics, capabilities, and behaviors and on the ModSAF user interface to improve the ease of the human console operator's interaction with the ModSAF and to allow the human operator to get the most out of the ModSAF station.

A lesson learned during STOW-E in the use of ModSAF's POP led WISSARD to ensure that its ModSAF workstations used discrete POP database numbers. It was discovered that any machine generating ModSAF on the entire DSI network would attempt to take advantage of unused processor operations of any other ModSAF workstation on the network using the same POP ID. Specifically, IDA was generating ModSAF entities by using unused processor operations from a WISSARD machine on the same (default) POP database ID.

The 2E6 is a classic case of using a "Legacy" training system in a DIS environment. As a result, the use of the 2E6 in the STOW-E scenario attempted to optimize its capabilities and not put it in situations where it would be at a disadvantage due to equipment limitations. For example, the 2E6 only "sees" (radar and visually) four targets in the integrated mode and two targets in the independent mode. It chooses the closest four targets. These limitations make missions involving strike escort

difficult since the strike aircraft take up the four slots and don't drop out until bogey aircraft get closer to the 2E6 than the strike package. That makes for extremely short opportunity ranges and negates the advantage of the long-range missiles, and in some cases, even the medium-range missiles. The bogeys obviously are not constrained to seeing the closest four targets. This problem will likely not go away without significant upgrades to the simulators.

WISSARD ran phone lines into the domes to permit the controlling agency to talk directly to the aircrew. However, there was so much noise in the domes that it was extremely difficult to hear any of the communications. The solution was to only have the radar intercept officer on the phone net. He then passed the information (via ICS) to the pilot and built the situation awareness for the section.

Equipment was procured for the express purpose of integrating the phone system directly into the cockpit headset (normal UHF comm) system. This equipment was not used due to a number of factors such as: (1) negative comments from TACCSF on its experience trying to do the same thing; (2) it appeared to be an invasive, time-risk procedure that WISSARD personnel were not comfortable tackling, given the pace of pre-STOW-E testing; and (3) the 2E6 Contractor Operation and Maintenance Systems contract had just been let and their personnel were just getting up to speed and were not available to help in the implementation. The communication issue should be resolved for follow-on Advanced Concepts Technical Demonstrations (ACTDs) to keep it from being such a detractor from the aircrew perspective.

There were good comments from all crews: This training capability represents a quantum leap above what exists in the 2E6 as a stand-alone trainer. The ability to operate in mixed section as well as mixed divisions versus human-in-the-loop threats and automated (IFOR) threats is unparalleled. The ability to fly formation on live, virtual, and Computer-Generated Forces (CGFs) seamlessly was demonstrated on numerous occasions—a real attention getter for all participating aircrews. On numerous occasions, the 2E6 was able to fly with and/or against the F-16 Falcon Star from Germany, the F-16s out of Armstrong Lab, the F-18 Manned Flight Simulator (MFS) from Patuxent River, and the F-15 from Kirtland AFB.

The communication problems experienced in the 2E6 remain for the BATTs but to a lesser extent. The noise problem encountered by the BATTs was more a result of conversations by people in the room (the BATT is located in the main WISSARD lab room) overpowering the volume level of the phone patch. WISSARD needs to find a way to either boost the phone signal (WISSARD already tried in-line amplifiers) or run the signal through the BATT voice hardware that is used to talk between the 2E6 and the BATTs in the integrated mode.

Currently, the BATT can only see (radar and visually) the closest six air entities. This is not as limited as the 2E6. The BATT's original developer has indicated that display of entities in excess of 15 is possible. The current limitations regarding the TDB (currently only NAS Fallon and China Lake), and the entities (currently only six) can be corrected. A key consideration is the cost versus the value added.

3.7 INTELLIGENT FORCES

3.7.1 Introduction

IFORs stands for automated Intelligent FORces. Ideally, IFORs allow replacement of human control of selected units on the simulated battlefield by automated control without noticeably degrading the appropriateness of the resulting behavior. In practice, this ideal can be quite difficult to achieve. However, experience with the current fielded state of the art in this area (the semi-automated forces

[SAFORs] in SIMNET and its immediate successors) suggests that even very approximate IFORs can improve the realism of simulated engagements. The principal reason is that, when there are not enough humans (and associated simulators) available to fully populate the battlefield, populating it with even "dumb" IFORs yields more realism than would leaving it inappropriately unpopulated. The WISSARD facility provided not only ModSAF to the STOW-E demonstration/exercise but also IFORs.

3.7.2 Goals

The following were IFOR goals for participation in STOW-E:

a. Participate in a large-scale operational exercise. The goal here was to test whether the software was sufficiently mature to work in such a large exercise over an extended period of time.

b. Learn what is required for theater-level exercises. Earlier work had been in very limited scenarios with very little exposure to how the work fits into a complete theater-level exercise.

c. Provide viable IFOR opponents for human and ModSAF forces.

d. (Knowledge Acquisition). Learn about what is required for more advanced IFOR opponents in air-to-air and air-to-ground combat.

3.7.3 Results

3.7.3.1 Participation. IFOR vehicles were successfully fielded for every scheduled event (10 events, approximately 32 vehicles) and in many unscheduled events (5 to 7 events, approximately 16 vehicles). Air-to-air missions were performed against ModSAF and humans in the BATTs and the 2E6. The attempt was made to engage planes from other sites, but they never reacted to the IFOR planes and would typically fall off the net before the IFOR planes could get off missile shots. The IFOR planes did, however, participate in air-to-ground (bombing bridges, etc.) and air-to-surface (firing missiles at ships) attacks in which there were successful engagements with ground and surface targets from other sites.

There were a limited number of software failures with the most significant being the inability to fly over the TDB where the ground battle was raging when it was populated with hundreds of tanks. There was no problem flying over the TDB when it was not populated with tanks—this was tested when Europe was off-line.

Possibly the best example of successful IFOR participation was in the execution of an unscheduled event for the second day. In this mission, a section of F18s were to perform a ground attack against the Star Islands. IFOR planes were used in place of a virtual (manned) ground attack because of the failure of the simulator. Enroute to the target, the planes were unexpectedly intercepted by ModSAF MiG-29s. The F18s engaged the MiG-29s to defend themselves and got off one or two shots (but no kills). The MiG-29s either disappeared (fell off the net) or disengaged, and the F18s reinitiated their air-to-ground attack. Further enroute, they were unexpectedly fired on from a surface-to-air site, killing the wingman. This was an unscripted iteration since no surface-to-air systems were scheduled to participate in STOW-E. The lead continued on, successfully dropping bombs on the designated target and then egressing back to base.

3.7.3.2 Learn About Theater-Level Exercises. STOW-E was an excellent educational experience in terms of what is required of IFOR vehicles for these large-scale exercises. IFOR vehicles need to be more flexible in performing their missions. The IFORs required more effort to set up for a mission than the ModSAF vehicles, and there was less flexibility in retasking them during a

mission; however, they did run completely autonomously during their missions, and didn't require continued monitoring as did ModSAF. Mission entries need to be made as easy or easier than ModSAF, and retasking the IFORs should be made easier if a mission needs to be changed.

3.7.3.3 Provide Viable IFOR Opponents for Human and ModSAF Forces. Overall, viable IFOR opponents were provided. However, it was difficult to evaluate the "skill" of IFOR planes due to problems with the underlying simulation models. Day 1 performance of IFOR planes in engagements was frustrating. The planes were easily shot down by ModSAF F/A-18s. It was discovered that the ModSAF F/A-18s were carrying Phoenix's, which would be contrary to real life. In engagements with humans, the IFOR vehicles would often get into good tactical positions only to see the missiles miss when they were shot. There were some kills against both the BATT and 2E6s, but in general, the IFOR vehicles got "toasted." The primary cause of the misses is suspected to be due to fundamental flaws in the ModSAF missiles.

3.7.3.4 Knowledge Acquisition. The structure of STOW-E made it impossible to do controlled knowledge acquisition, but the interactions that did arise allowed for spontaneous knowledge acquisition. In the future, it is clear that the WISSARD site will be able to be used for significant knowledge acquisition although the classification of the 2E6 domes will continue to be a hindrance.

3.7.4 Summary of Primary Problems to Address

3.7.4.1 Overall Computational Requirements. One disappointment was in the number of IFOR vehicles that could effectively be run on a single machine during these engagements (maximum of four). The system needs to be reviewed from top to bottom to find out what the problems were. The processing of vehicles that are not directly relevant to a plane's mission need to be filtered out as early as possible. This may require modifications to ModSAF, the Soar architecture, and/or the knowledge encoded in the Soar/IFOR agents. The possibility for Soar/IFOR agents to run on just SAF Sim, eliminating the overhead of the graphical user interface, will be looked into. Future exercises will require much more computational power.

3.7.4.2 Interfaces for Defining and Retasking Missions. The construction of new interfaces is about to begin. STOW-E provided useful input for the requirements of such interfaces.

3.7.4.3 Improvement in ModSAF Missile and Airframe Models. ModSAF missile and airframe models need to be improved.

3.7.5 Goals and Plans for Future Exercises

This was an extremely useful exercise. However, it is not clear that a repeat of this type of exercise in 6 months would be of much value. An exercise stressing command and control of close-air support missions would be useful in 6 months to a year. Also in a year, a more limited exercise involving rotary-wing aircraft anti-armor would be useful. Although the 1500 ground entities stressed the network and the underlying software, smaller exercises (battalion level) that involved a range of systems (air, ground, air-to-air, air-to-ground), would be most useful over the next year with exercises of 10K entities being scheduled for 18 months or so.

3.7.6 Significance of IFOR Participation

This exercise has the additional significance of demonstrating that "hardcore" AI technology can be successfully used in an operational exercise. This is one of the first (if not the first) time that an AI system has been used in this way. This demonstrates a real success of taking technology developed under ARPA research programs (6.1, 6.2) and having an impact on the operational side.

4.0 TECHNIQUES

4.1 EXPERIMENTAL PROTOCOL DATA UNITS

4.1.1 Introduction

In the development of STOW-E, a number of experimental PDUs were developed at NRaD and the Naval Underwater Warfare Center (NUWC) to supplement those PDUs defined in the DIS protocol standard. The 200 series PDUs listed below (Application Gateway-to-Gateway Protocol) were used to reduce the number of standard PDUs sent on the DSI. This reduction allowed for data to be exchanged between sites within an effective bandwidth of 1.1 Mbps. This limitation was imposed on STOW-E by hardware components of the DSI. The following PDUs were sent over the DSI in addition to those available from the standard.

4.1.1.1 Experimental PDUs Developed by NRaD

#133 Aggregate PDU Kind

This PDU provides an aggregate, hierarchical representation of DIS entities. It provides the mechanism to pass aggregate data so that commanders sitting at "2-D" battle monitoring stations can see the entire battlefield, and so that AAR systems can record the positional data, hierarchical data, and aggregate combat power of all units in the battle for later playback and review.

#150 Marker PDU Kind

This PDU is used to describe the parameters necessary for using Minefield Markers. The information includes location, orientation, update frequency, and type of marker (mine, breach, etc.).

#200 Subscriber

This PDU is sent from each site upon startup to notify other sites that it is a participant. It defines the subscriber's address.

#201 Master Grid

This PDU is sent from the "start up" site to define the playbox latitude, longitude, altitude, and grid information where the exercise is to be conducted.

#202 Packet Rate

This PDU is sent when there is a change in bandwidth percentage for Load Leveling.

#203 Control

This PDU is sent when there is a change in the enable/disable status of Grid Filtering, Load Leveling, Compression, or Bundling.

#204 Grid Subscriber

This PDU is sent to notify other sites when there is a change in grid locations of interest to a site. It contains the address of the sender, the destination, and the number and the location of changed grids.

#206 Compressed Entity State (ES)

This PDU is sent in place of the standard Entity State PDU when Compression is enabled.

#207 Bundled

This PDU is sent when Bundling is enabled. It defines the number of PDUs bundled and the data in the bundle.

#208 Request ES PDU

This PDU is sent if a Compressed PDU has been received, but a full PDU has not been stored, and a full update is necessary.

#210 Quiescent Request

This PDU is sent when an entity deemed quiescent cannot be located in the LAN or the information stored for that entity ID does not indicate a quiescent entity.

#211 Quiescent State Change

This PDU is sent periodically or when there is a change in a Quiescent Entity List.

#212 Quiescent Full List

This PDU is sent periodically to establish reliable data transfer.

#213 Summary ES PDU

This PDU is sent upon receipt of a Quiescent Entity PDU (#210) to provide the most current data for a specific entity.

#214 Reliable

This PDU is sent to Acknowledge receipt of a specific entity.

#215 Delete

This PDU is sent to Not Acknowledge receipt of a specific entity.

4.1.1.2 Experimental PDUs developed by NUWC

#171 Underwater Acoustic

This PDU is sent to define Active Emissions and Passive Signatures of specific entities.

#173 Transfer Control Request (Hand Off Request)

This PDU is a request to a site to take control of a specific entity.

#174 Transfer Control (Hand Off)

This PDU is sent in response to the Transfer Control Request (#173) acknowledging that control of a specific entity has been taken by another site.

#175 Transfer Control Acknowledge (Hand Off Acknowledge)

This PDU is sent to acknowledge receipt of a Transfer Control (#174) PDU.

4.2 SECURITY

4.2.1 Overall

STOW-E was executed as a multi-security-level exercise. Unclassified, US1, and Secret NOFORN simulation sites were linked together over the DSI during STOW-E via one-way data links. Motorola's Improved Performance Network Encryption System (INES) was used to provide National Security Agency (NSA) approved encryption at the Secret level between classified sites.

4.2.2 DSI Security

All data from Red (classified) STOW-E sites was assumed classified at the Secret level unless a memorandum from the site facility manager was received affirming no classified data was entered into the network from that site.

The Security Guard included a modification to existing network architecture allowing multi-level security. An Allied Telesis CentreCOM fiber-optic hub/repeater (P/N 3606F-15) and an Allied Telesis CentreCOM fiber-optic transceiver (P/N AT-MX26FL) were used as an NSA-approved data diode, permitting unclassified data to be bridged into classified spaces while preventing classified data from passing out to unclassified sites. Thus, classified STOW-E sites were able to view and interact with entities generated at unclassified sites in a limited way. Unclassified sites were unable to see or interact with any entities generated by classified sites.

INES operations were managed by DSI personnel. This included configuration disk and key management as well as coordination of daily rekeying times. This required close operational coordination between DSI and SEAF Technical Control. DSI operations were coordinated and controlled via the Network Operations Center (NOC) in Ft. Leavenworth, Kansas, and the alternate (STOW-E) NOC in Alexandria, Virginia.

An effort was made to proceed, to the greatest degree possible, within a paperless environment, in regard to security. Although some security documents were mandatory, by minimizing the amount of paperwork required for secure STOW-E operations, the entire process was greatly streamlined.

Security Memorandums of Agreement (MOAs) were signed between each DSI site and DSI management and also between each STOW-E back-door site, its DSI front-end node, and DSI management. Sites originally nominated for STOW-E participation went through a maturation process with respect to the following aspects: people, procedures, data, hardware, software. Final sites were those that eliminated all risk categories.

4.2.3 Lessons Learned

One of the security lessons learned during STOW-E was that although both the technical and scenario conference calls were unclassified, no concerted effort was made to ensure that the conversations held over these lines were, in fact, unclassified. Although no classified conversations were actually conducted over the nonsecure conference call during STOW-E, this remains one area for improvement during future exercises using clear conference calls for technical and force coordination. Future use of digitized voice over the secure DSI or the use of STU-III telephones may alleviate this potential security risk.

4.2.4 STOW-E Evaluation and Analysis Facility (SEAF)

A security manager was assigned the following responsibilities:

a. Provide secure mailing support for classified STOW-E documents and data logger tapes.

b. Facilitate badging, escorts, and clearances. Organize a master list of all local participant personnel. Visitation badges were of the following types:

   1. Escort required.
   2. Limited access to SEAF and SIMNET.
   3. Unlimited access (not necessary for most participants).

c. Provide perimeter control (razor wire surrounded the SEAF).

d. Provide 24-hour guards at SEAF entrances.

e. Coordinate VIP visits (daily visitor list).

f. Execute disk sanitization/chip destruction at the end of STOW-E. (Provided certifications of destruction and disk erasure prior to shipping. Provided Customs forms for overseas equipment shipping.)

4.2.5 Black Sites

N/A.

4.2.6 Red Sites

The following is a list of criteria that all Red sites met for STOW-E.

a. *DSI node installation/training*: All DSI nodes were installed by qualified DSI personal, and DSI hands-on training was made available to all STOW-E participants. This training was strongly recommended and proved to be highly useful for network coordination and troubleshooting prior to and during STOW-E.

b. *INES training:* Highly useful 1-week training (ARPA sponsored) covering encryption devise use and operation. Attendance at a 3-day Motorola INES course in Phoenix, AZ, for at least one individual at each Red STOW-E site was also recommended.

c. Individual facility authorization to operate in a dedicated mode (listed in MOA): Each DSI node site agreed to dedicate the use of all DSI equipment during STOW-E to the actual tasks of STOW-E.

d. Communications security Material Systems (CMS) accounts in place and trained, approved CMS personnel in place and available at all Red STOW-E sites.

e. Personnel access lists for all secure areas in place.

f. NES configuration disks and keys distributed from DSI management.

g. NSA-approved classified storage available at all Red sites.

h. Site visitors: Red site clearances and Black visitor requests were sent prior to the beginning of STOW-E testing.

4.2.7 Results

The Security Guard worked as planned, designed, approved, and engineered. Early recognition of security issues and appropriate, early, and thorough action to mitigate security risks were

instrumental in making security a non-issue for STOW-E. However, for future STOW demonstrations/exercises, the INES and the Guard should be reviewed to determine if they are adequate for large and more complex exercises. They probably are not sufficient.

4.3 TACTICAL COMMUNICATIONS

4.3.1 Introduction

This section describes the communications, external to the simulation data network, connecting the simulations/simulators and live sites required to provide simulated Tactical Radio Nets. These communications simulate, as realistic as possible, the Tactical Radio nets that would be in use in a Theater of Operations. Also provided for were any Data Links that were not subsumed in the simulations or simulators. The communications described here were over and above that provided by the participating units' organic equipment. Further, communications that were internal to the participating facilities were not considered. This section, in addition to describing the configuration, evaluates the performance of the process and planning for the Tactical Communications.

4.3.2 Configuration

The purpose of the Support and Tactical Communications was to provide the nondata communications support required for the demonstrations. The Nets were organized to simulate Tactical Radio Nets that would be found in use by the Tactical units simulated. These nets are normally HF/VHF/UHF clear voice and l/2 duplex; push to talk. This operation was accommodated by providing audio teleconference calls to replicate the nets using DSN and FTS bridges. Commercial conferencing was to be used if the preemption rate was high or intolerable.

Each subscriber normally used a standard speakerphone. In some cases, where the activity was predicted to be high a particular site and high ambient noise existed, a headset was provided. A headset was provided for personnel using consoles or operating simulators. The default mode for the subscriber was to have the speakerphone on and muted. The muting was very important to keep the background noise on the net at a minimum. When a subscriber was active, the built-in microphone or the handset could be used. For some Tactical Communications Nets, actual connection into the headsets of simulators was provided.

4.3.3 Evaluation

4.3.3.1 Planning. The generation of the Tactical Communications Plan was completed without undue effort. The primary inputs were the scenarios and Order of Battle for the demonstration. The gathering of the telephone numbers to be used during the test was the major challenge. Many sites had to procure additional lines, so the numbers were provided at the last minute. Since there was no extra effort required after receipt of the numbers and actual implementation of the nets, this did not present any problem. The number of revisions was high since the sites rearranged their facilitates from time to time. All in all, the planning went well.

4.3.3.2 Implementation. The implementation was accomplished by using the DSN for all conference calls involving overseas subscribers. FTS was used to support all CONUS-only conference calls. MCI Forum was available for backup. The reason DSN was used was cost considerations and because FTS does not cover outside CONUS calls. The original plan was to use DSN for all conferences, but it became apparent during the preparatory tests that the conference operators would not be able to handle all of our conferences at the peak of the demonstration, as well as the other normally occurring conference calls. It was then decided to use FTS even though it was not reimbursable.

The implementation was technically acceptable in that the conference bridges worked, and the connectivity was achieved with few problems. The shortcomings will be discussed below. As far as the terminal equipment was concerned, the sites used speakerphones with mute switches. In the case of *Hue City*, cellular phones were used.

4.3.3.3 Shortcomings. The use of the speakerphones did not replicate normal tactical radio equipment and, in that sense, was somewhat unrealistic. To provide for tactical hardware would have required additional engineering effort and hardware cost.

None of the circuits was covered; hence the voice communications were "in the clear." In some instances had secure voice been provided, more realism could have been achieved. This was considered but, for STOW-E, was not warranted by the cost/benefit balance.

Use of the DSN caused preemption in some cases, which interrupted operations. Restoration had to be accomplished by the disconnected party. The conferences were established at the IMMEDIATE precedence level, and if a disconnected party was at a ROUTINE instrument, the party would be reconnected at ROUTINE precedence making preemption more of a recurring possibility. Otherwise the operator had to disconnect the party and reconnect at the IMMEDIATE level creating inordinate delays. Overall, however, preemption on DSN was minimal (10 to 15%).

The lack of training for the Voice Net Control Stations (NCSs) caused confusion and conflicts at the beginning of testing. On the job training was used to bring the various Nets on line. Had some formal training been provided, this could have been smoother. By the time the demonstration was started, the NCSs were adept at their tasks.

4.4 TECHNICAL CONTROL

4.4.1 Introduction

This area of responsibility entailed functions relating to the operation of STOW-E hardware and software located in the SEAF at Grafenwoehr, Germany, and at participating sites, with the exception of communications and data analysis functions.

4.4.2 SEAF Technical Control Stations

SEAF Technical Control was defined by the stations manned during STOW-E. These stations and their functions were as follows:

4.4.2.1 Technical Control Manager. This position had overall responsibility for the technical control section of the SEAF and technical coordination of all network participating sites. This responsibility extended to a high-level defining of objectives directly supporting STOW-E program goals. The Technical Control Manager managed resources (fiscal, equipment, personnel, and schedule) and provided program review continuity in the technical control section area. During test, technical, and exercise periods, the Technical Control Manager was located at the SEAF, the NOC, or any other participating site. When the Technical Control Manager was not at the SEAF, the Technical Control Supervisor performed the SEAF on-site functions.

4.4.2.2 Technical Control Supervisor. This position was responsible for directing and coordinating the activities of all participating sites and of the SEAF. This included arranging, initiating, and maintaining technical control and engineering conference calls; ensuring DSI reservations were made by the DSI Network Manger for test and scenario events; conducting all planned technical test

events as listed in the appropriate test plans and procedures; and preparing narrative logs and reports after completion of technical test events.

4.4.2.3 Network Supervisor. The Network Supervisor was responsible for overall network operations and continuity, including supervising equipment procurement, shipment, installation, and checkout; software management including managing the Application Gateway engineers and coordination with DIS engineers; maintaining site ID number status; and coordinating technical operations with test operations directed by the Technical Control Supervisor.

4.4.2.4 DSI Operations Engineers. This position provided hardware and software support for unclassified and classified operations including equipment procurement, shipment, installation, and checkout. During SEAF operations, the DSI Operations Engineers ensured continuity of the unclassified and classified networks through system monitoring, operation, and troubleshooting, as well as by close coordination with the NOC. DSI engineers were responsible for INES operations on the classified networks including initialization and configuration disk management; and for Video Teleconferencing (VTC) equipment, operation, and scheduling.

4.4.2.5 Application Gateway Engineer. This position was responsible for supporting the AG software at the SEAF and other sites, to include software debugging, writing necessary software patch programs, configuration management and documentation. This engineer was also responsible for monitoring AG performance and evaluating AG software performance, and providing application gateway technical support to site general engineers.

4.4.2.6 Net Visualizer Analyst. This position supported the real-time monitoring and collecting of traffic load data at each site on the network in direct support of the Network Supervisor and DSI Operations Engineers, as well as for subsequent data analysis to assess network performance. This analyst also supported occasional tour discussions of the Net Visualizer functions and how these functions supported network operations.

4.4.2.7 Stealth Operator. This position supported the Technical Control Supervisor and scenario direction by operating a 3-D display of any aspect of the battlefield. Actions ranged from tagging onto an individual combat unit to scanning large areas of the battlefield. The Stealth Operator also supported all appropriate inquiries from other SEAF participants, as well as tour individuals and included illustrating the capabilities and uses of the 3-D display and explaining battlefield activities. These responsibilities required the Stealth Operator to remain up-to-date on scenario and interaction activities.

4.4.2.8 Army Site Status Projection Operator. This position ensured that status projection information was current and complete for all Army operations so that it could be used by all other sections (Headquarters and Administration Support, Operations, Scenario, and Communications Control). The operator was also charged with using this projection to brief varying levels of tour participants, both military and civilian.

4.4.2.9 Navy Site Status Projection Operator. This position ensured that status projection information was current and complete for all Navy Operations so that it could be used by all other sections (Headquarters and Administration Support, Operations, Scenario, and Communications Control). The operator was also charged with using this projection to brief varying levels of tour participants, both military and civilian.

4.4.2.10 Air Force Site Status Projection Operator. This position ensured the status projection information was current and complete for all Air Force operations for use by all other sections

(Headquarters and Administration Support, Operations, Scenario, and Communications Control). The operator was also charged with using this projection to brief varying levels of tour participants, both military and civilian.

4.4.2.11 Technologies Status Projection Operator. This position managed the technologies status display showing operational states of the merging technologies being used in STOW-E. This position required in-depth knowledge of these technologies to respond to inquiries from a variety of tour participants. Such technical briefs accommodated varying levels of tour participant knowledge and interests.

4.4.2.12 Stealth 3-D Naval Shipping Operator. This position supported the Technical Control Supervisor and scenario direction by operating a 3-D display of the naval operating area. Duties ranged from tethering onto individual ships to scanning large areas of the ocean. The Stealth 3-D Naval Shipping Operator also supported all appropriate inquiries from other SEAF participants, brief groups, and individuals and was called on to explain the capabilities and uses of the 3-D display as well as naval shipping activities. These responsibilities required the Stealth 3-D Naval Shipping Operator to remain up-to-date on scenario and interaction activities.

4.4.2.13 Stealth 3-D Navy/Air Force Operator. This position supported the Technical Control Supervisor and scenario direction by operating a 3-D display of the Navy/Air Force aircraft operating area. Duties ranged from tethering onto individual aircraft to scanning large air operations areas. The Stealth 3-D Navy/Air Force Aircraft Operator also supported all appropriate inquiries from other SEAF participants, brief groups, and individuals and was called on to explain the capabilities and uses of the 3-D display as well as Navy and Air Force activities. These responsibilities required the Stealth 3-D Navy/Air Force Aircraft Operator to remain up-to-date on scenario and interaction activities.

4.4.2.14 DSI Network Status Projection Operator. This Operator ensured the status projection information was current and complete for all DSI operations for use by all other sections (Headquarters and Administration Support, Operations, Scenario, and Communications Control) and was responsible for using this projection to brief varying levels of tour participants, both military and civilian.

4.4.3 Briefing Operations

Descriptions of STOW-E technologies and techniques were necessary when considering the aspects of program verification and exposure to actual and potential users of STOW-E technologies. A comprehensive effort in demonstrating STOW-E concepts was directed in the SEAF by the Operations Section and consisted of static and dynamic displays supported by the on-going exercises and scenarios and a team of trained briefers. Briefers, assisted by members of the Technical Control Sections, performed functions within their areas of responsibilities to support individual briefing concerns and questions. Members of the Technical Control Team remained aware of how their areas of responsibility supported both the SEAF and STOW-E concepts and goals and were able to articulate such information to individuals and groups. All Technical Control Team members reviewed each day's expected Joint Visitors Bureau requirements prior to assuming their duties and were prepared for unannounced briefing requirements.

4.5 DATA COLLECTION AND ANALYSIS

4.5.1 Background

STOW-E analysis was divided into three areas: technical analysis, real-time and after-action scenario review, and operational analysis. Technical analysis addresses the performance of the DSI

network and the various systems and simulations operating on the network. Real-time and after-action scenario reviews assess the execution of the military scenario. Operational analysis addresses the effectiveness of the military training of the demonstration.

NRaD's data analysis efforts were focused on technical issues. Technical analysis included the assessment of the performance of the AG, the characterization of DIS traffic, and the estimation of delays across the network. The individual site DIS data log files, which were recorded at most sites, are available to support military after-action reviews. Los Alamos National Labs is merging individual site files to construct complete, ground-truth log files for selected portions of STOW-E. This composite file will also support military after-action review. Operational analysis is being conducted by the 7th Army in Grafenwoehr, Germany, and by designated Navy and Air Force analytical facilities such as the Center for Naval Analysis (CNA).

4.5.2 Data Collection

4.5.2.1 Site Configurations. The NRaD DIS Data Logger (DLogger) was used to record the DIS traffic during STOW-E. Data was recorded on the local simulation LAN at each STOW-E site (with the exception of Dahlgren). A DLogger, running on an SGI platform, was a node on the local LAN and was configured to record all appropriate DIS traffic (exercise ID 3 for Red sites and 2 for Black sites). The recorded data thus consists of the data generated locally and the data presented to the LAN via the AG. Table 4-1 lists all DLogger sites. Figure 4-1 illustrates the configuration of a typical Red STOW-E site.

Table 4-1. DLogger Sites.

Red DLogger Sites	Black DLogger Sites
TACCSF (Albuquerque, NM)	AVTB (Ft. Rucker, AL)
NUWC (Newport, RI)	SIMNET (Grafenwoehr, Germany)
WISSARD (Virginia Beach, VA)	
BFTT (Damneck, VA)	
SEAF (Grafenwoehr, Germany)	
IDA (Alexandria, VA)	
NAWC (Cherry Pt., NC)	
MFS (Patuxent River, MD)	

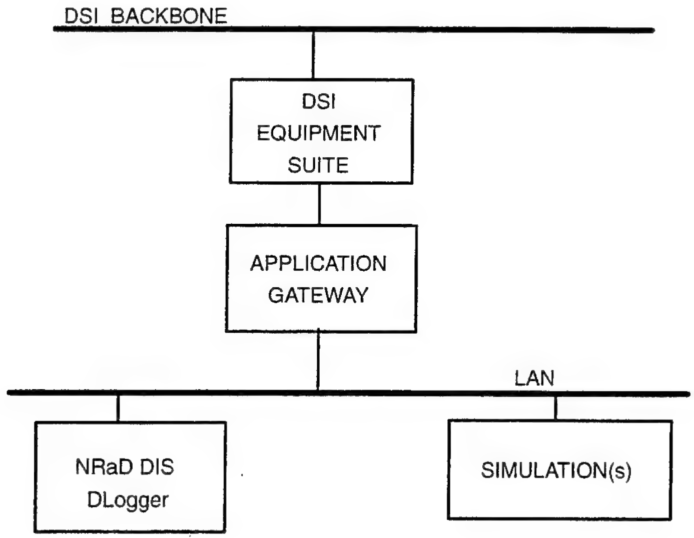

Figure 4-1. Typical Red site configuration.

In addition to recording simulation LAN traffic, the two Black sites (Ft. Rucker and SIMNET) logged data on the WAN side of the AG. This was done using a slightly modified DLogger. This second logger, the AGWANReceiver, recorded all UDP port 3000 traffic. The intent of logging this data was to provide a means of directly analyzing the performance of the AG at these two sites. Figure 4-2 illustrates the configuration at the two Black sites.

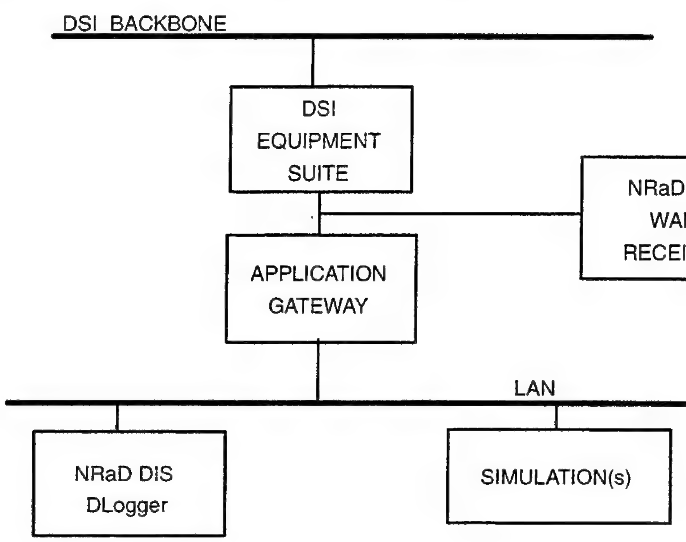

Figure 4-2. Black site (Ft. Rucker and SIMNET) configuration.

The SEAF, in Grafenwoher, Germany, also logged selected LAN and WAN network traffic using SGI's Network Visualizer software. The configuration at the SEAF is illustrated in figure 4-3. BBN monitored loads, packets dropped, errors, etc., by using its Advanced Network Monitoring tool.

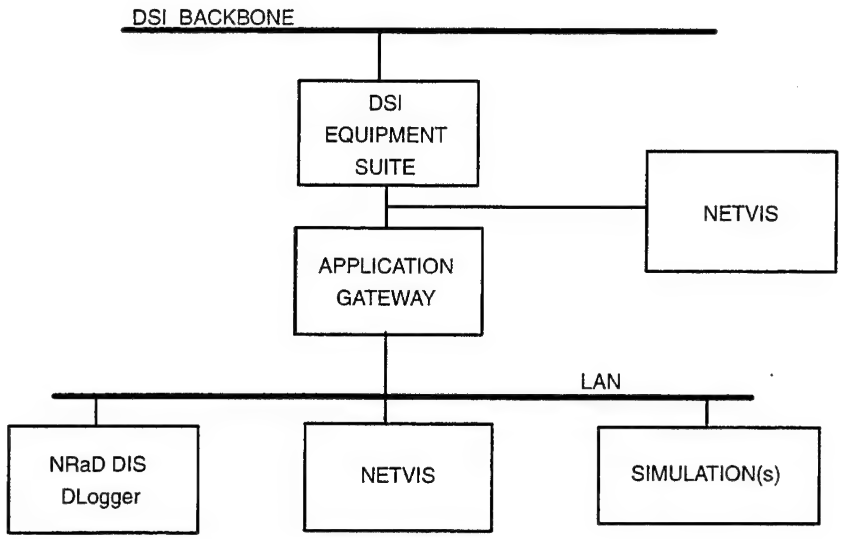

Figure 4-3. SEAF configuration.

4.5.2.2 DLogger Specifics. DLogger records DIS PDUs along with a time-stamp corresponding to when the PDU was detected by on the LAN. This time-stamp is crucial to the accurate analysis of the log files. Comparing this time-stamp to the time-stamp found within the data of the DIS PDU is a means by which a simulator's PDU generation rate can be verified. This technique was used in Newport to confirm that PDUs from a particular BFTT entity were being heard on the NUWC LAN at the proper ~5-second heartbeat interval. The DLogger time-stamp also makes possible the realistic playback of PDUs from a log file.

4.5.3 Technical Analysis

4.5.3.1 Bandwidth-Demand Reduction Techniques (BRTs). The bandwidth-demand reduction techniques (BRTs) were housed in the AG component of the DSI network. The function of these algorithms in STOW-E was to reduce the DIS traffic load offered to the DSI WAN. The performance of the STOW-E AG will be assessed from the following viewpoints:

a. Overall AG system performance

b. AG performance at selected individual sites

c. Performance of individual AG algorithms

"Real-time" estimates of overall AG system performance, as well as the performance of some individual algorithms were collected during STOW-E. See section 3.3 for this data.

4.5.3.2 Characterization of the DIS Traffic. Characterization of DIS traffic loads is critical for network bandwidth allocation in future DIS exercises. DIS simulation load is a function of the simulation system, the number and types of entities being generated, the entities' levels of activity, and the dead-reckoning algorithm being used. Samples of STOW-E traffic will be so characterized. This analysis will include initial correlations of load with the military scenario.

4.5.3.3 Network Delay. DSI network delay will be estimated for selected segments/periods of the STOW-E exercise. Due to the volume of STOW-E data collected (approximately 24 Mb) and the time required for its analysis, a separate data analysis report will be published at a later date.

4.6 TEST AND INTEGRATION

4.6.1 General

Test and Integration covers the STOW-E test efforts from April through November 1994 including: STOW-E planning meetings, Subsystem Integration Tests (SSITs), Review and Planning meetings, Functional Validation (FV) Tests, System Integration Tests (SITs), and the STOW-E technology demonstration.

4.6.2 Original Test and Integration Plan

The integration of sites for STOW-E was originally planned as generically as possible to accommodate the introduction of new technology and individual site requirement changes that were anticipated to occur throughout the test effort. As the SSITs were accomplished and requirements became more clearly defined, associated documentation became more detailed and specific. This worked well as a point of departure and supported the STOW-E test and integration process. As emerging requirements became known and modifications to existing requirements became more clearly defined, they replaced the generic statements in the test plan and procedures. Many of the detailed/specific requirements were not available when the test and integration process began.

4.6.2.1 Planning Meeting. The Naval Command, Control and Ocean Surveillance Center (NCCOSC) RDT&E Division (NRaD) hosted a STOW-E program planning meeting for all site representatives. During this meeting, the System Engineering and Integration (SEI) Test Coordinator outlined the plan for the STOW-E Test and Integration effort. The test organization was introduced, test terms and milestones were identified and defined, SEI points-of-contact were established for each of the known participating sites. Unique site requirements and current schedules were requested from each site. Tentative scheduling for all tests were distributed to all site representatives in attendance. The testing described included Unit Testing, DIS Version 2.0.3 Compliance Testing, Subsystem Integration Testing, and System Integration Testing.

4.6.2.2 Requirements Development. A preliminary test requirements list was developed using the STOW-E System Requirements Document as a starting point. Exit criteria and measures of success were developed specifically for each requirement. Site modifications were planned to be incorporated as the Test Coordinator received them.

4.6.2.3 Test Plan/Procedure Development. The test plan and procedure format evolved out of the preliminary meetings. This format included the following sections: General, Dates, Times, Scope, Concept, Test Objectives, Test Execution, System Failure Procedures, Exercise Support, and Appendices. This document was distributed to all sites. In the beginning, the document was fairly small and was distributed to participating sites via telephonic facsimile. As the document necessarily grew in size with the addition of sites to each test period, it was more expedient and/or cost effective to use Federal Express and/or US Express Mail. The final process involved distributing the documents using the File Transfer Protocol (FTP) on the DSI Network and/or the Internet, which proved much more practical and effective.

4.6.2.4 Supporting Reference Notes. Supporting reference notes were compiled for each site showing the Points of Contact (POCs), DSI node status, entity-generation capability, DIS-compliance status, and DSI node IP addresses. The site POCs were used as addressees for distribution of e-mail, faxes, and test documentation.

Schedules were developed and maintained to show upcoming events such as SSITs, major concurrent military exercises, scheduled site participation, and site DIS node installation status. Master

schedules were generated and displayed at NRaD and used as the basis for test planning and coordination of associated activities.

4.6.3 Real-Time STOW-E Modifications

4.6.3.1 General. Flexibility became a major part of the test planning. As STOW-E became more visible, requirements changed. New technologies were incorporated as they were developed, or were enhanced after they were incorporated. These changes, though not foreseen in detail, were anticipated. Consequently, the STOW-E effort followed the original plan very closely. Changes were quickly incorporated to keep pace with the demands of meeting the STOW-E compressed time schedule.

4.6.3.2 Requirements. Requirements became more clearly defined as sites began to participate and test their systems. Requirements were also defined and modified by the presiding members of the Joint Services. Development/modification of requirements for hardware, software, and testing were constantly evolving. Requirements were kept current as new information was made available to the test team.

4.6.3.3 Schedules. SSITs were executed with only minor departure from the original plan. Three SSITs were extended in time from the original plan; one SSIT was added to the original plan; and the SIT was moved up and incorporated into SSIT #8. Table 4-2 shows planned versus actual test dates. It became extremely difficult to make plans and schedules, incorporate them into the test documentation, distribute them in time to allow for review and comment, and then incorporate those comments and redistribute the revisions to all sites before the actual test was executed. Future scheduling should learn from this lesson and allow additional time between scheduled test periods.

Table 4-2. Test schedule summary.

	Test Dates	
Event	**Planned**	**Actual**
SSIT #1	5–7 April	5—7 April
SSIT #2	17–19 May	17—19 May
SSIT #3	8–10 June	21–23 June
SSIT #4/FV-1	11–15 July	8–15 July
SSIT #5	8–12 August	8–12 August
SSIT #6		25–30 August
SSIT #7/FV-2	12–16 September	9–17 September
SSIT #8	3–7 October	3–7 October
SIT	11–13 October	
FV-3		23–27 October
STOW-E	4–7 November	4–7 November

4.6.3.4 Site Changes. The original list of sites was developed based on the known schedule of site availability and DIS 2.0.3 compliance readiness. Table 4-3 shows the original list of sites compared to the actual list of sites participating in STOW-E. Sites are shown with their abbreviated name and site location.

Table 4-3. STOW-E sites.

Planned	Actual
ACMI, Nellis AFB, Las Vegas, NV	AEGIS, Mayport, FL
AEGIS, Mayport, FL	Armstrong Lab, Williams AFB, AZ
Armstrong Lab, Williams AFB, AZ	AVTB, Ft. Rucker, Dothan, AL
Artillery, Ft. Sill, OK	BFTT, Dam Neck, VA
AVTB, Ft. Rucker, Dothan, AL	BBS, Hohenfels, GE
BFTT, Dam Neck, VA	CMTC-IS, Hohenfels, GE
BBS, Hohenfels, GE	IDA, Arlington, VA
CMTC-IS, Hohenfels, GE	NAWC-AD, Patuxent River, MD
Ft. Monroe, VA	NSWC-DD, Dahlgren, VA
IDA, Arlington, VA	NUWC, Newport, RI
NAWC-AD, Patuxent River, MD	Pentagon, Washington, DC
NRaD, San Diego, CA	RAF, Lakenheath, UK
NTCS-A, Orlando, FL	SEAF, Grafenwoehr, GE
NUWC, Newport, RI	SIMNET, Grafenwoehr, GE
Pentagon, Washington, DC	TACCSF, Kirtland AFB, NM
SEAF, Grafenwoehr, GE	TACTS, Cherry Point, NC
SIMNET, Grafenwoehr, GE	USAF Falcon Star, Grafenwoehr, GE
Spangdahlem, GE	WISSARD, NAS Oceana, VA
TACCSF, Kirtland AFB, NM	
TACTS, Cherry Point, NC	
Williams AFB, AZ	
WISSARD, NAS Oceana, VA	
Warrior Preparation Center (WPC), Einsiedlerhof, GE	

4.6.3.5 Test Plan/Procedures

4.6.3.5.1 Test Process. The original plan called for sites to successfully complete their own unit testing before being added to an SSIT. This was intended to preclude using valuable integration time to troubleshoot individual site simulators/simulations. Most sites complied and when problems were discovered they were, for the most part, unique to having other sites on the network (e.g., translator incompatibilities, database incompatibilities). DIS 2.0.3 compliance testing was originally planned to be completed using the methodology developed in the DIS testbed at the University of Central Florida (UCF). Some, but not all, DIS compliance testing was completed.

After SSIT #3, POCs attended a combined post-SSIT review and pre-SSIT planning meeting to discuss lessons learned during the last SSIT as well as enhancements needed for the next SSIT. These meetings proved beneficial for a quick evaluation, and for discussing the practicality of new ideas presented, and for providing much needed face-to-face meetings for participants.

4.6.3.5.2 Test Plan/Procedures Document. Each test plan was based on the most recent definition of project requirements. Changes from each SSIT were incorporated into the next test plan and procedures document. When sites did not send in their test requirements but did voice a need, the test team made its best effort to incorporate those needs. The test document distribution process was being modified as the test evolution unfolded and as new distribution methods became available.

4.6.3.6 Trouble Reports. A trouble report process was incorporated into the test effort. Any site or individual could write up a problem on the STOW-E trouble report (TR) form. The TR was submitted to NRaD for action/dissemination. The TR was entered on a database to track its progress. Each final test report included the TR log for that SSIT as one of the appendices. The TR log included in the Test Report for SSIT #8 has a compilation of all SSIT TRs from April through October.

4.6.3.7 Test Reports. During each SSIT, activity logs were kept with as much detail as practical for the log keeper. At the end of the day, all sites faxed their logs to NRaD, and the test team compiled a daily report. At the end of the test, a quick look report was written and distributed.

After the conclusion of an SSIT, a test report was written. Each test requirement for that particular SSIT was reviewed with respect to the established exit criteria and measures of success. Conclusions were summarized based on general and specific results. The DSI network reliability summary was also included. Appendices included such items as quick look reports, daily test logs, trouble report log, and acronyms.

4.6.4 Final Product: STOW-E

The test team duties for STOW-E were to provide support in the preparation and manning of the SEAF for the STOW-E demonstration. The test team originally planned for 24-hour coverage, which proved unnecessary. Manning hours were kept flexible to cope with changing requirements. Testers aided in hardware setup and installation, software loading and testing, support for the AG testing, manning the Technical Control telephone conference, sending out daily DSN telephone conference requests to the DSN Operator, keeping the daily activity logs, updating Army, Navy, and Air Force site status boards, helping with scenario development and replay, and other miscellaneous support.

4.6.5 Lessons Learned and Conclusions

4.6.5.1 Meetings. Even with all the last-minute meetings and last-minute changes, the final SSITs and STOW-E were not much different than originally planned. The meetings could have been minimized and time could have been better spent working the plan rather than replanning the work.

4.6.5.2 Test Bed. During the SSITs, the computer assets in the NRaD test laboratory were shipped all over the world to support hardware requirements at other sites. The end result of not having a stable test-bed environment for the NRaD test team was that the test team had to travel extensively to other sites.

4.6.5.3 Manning. Some SSITs were well-manned at all sites while other SSITs operated with only a skeleton crew at certain sites. The optimum test team size was five people. One person for Test Coordinator (to handle the conference call telephone and coordinate test activities at the site); one person to maintain the daily activity log; one person to operate the site's entity generator; one person to monitor/work network status; and one person to operate the 2-D/3-D visualization device for test confirmations.

4.6.5.4 Test Conduct. Time was often lost during test conduct because of software and hardware problems, scheduling misinformation, and/or telephone conference difficulties. Sites need to provide a dedicated test team to support testing. As the STOW-E demonstration neared, more sites apparently came to this conclusion since sufficient personnel became available and, under most circumstances, they were the same personnel each time. Each site must take the time to read and understand the test plan/procedures. A lot of time was wasted responding to questions when the answers were already in the test plan/procedures document.

4.6.5.5 Test Summary. All planned testing was accomplished in some form or another. Additional tests could have been planned and might certainly have been appropriate if the schedule had not been so compressed, if more equipment had been specifically earmarked for testing, and if more personnel resources had been available to support the additional tests.

While the use of trouble reports was an excellent procedure, their usefulness depended, to a great extent, on the attitude of the cited party. Those open to constructive criticism considered the procedure a valuable resource, took appropriate corrective action, and tended to perform well throughout the STOW-E project. Those who resented externally generated TRs often had difficulty at the integrated "system" level over the WAN.

When STOW-E ended, over 50 trouble reports remained unaddressed. Future STOW events should have a rigid requirement that all deficiencies cited in a TR be corrected before a site is permitted to continue its participation in WAN testing.

5.0 ACRONYMS AND ABBREVIATIONS

2-D	Two-dimensional
3-D	Three-dimensional
AAR	After-Action Review
AAW	Anti-Air Warfare
ACM	Air Combat Maneuvering
ACMI	Air Combat Maneuvering Instrumentation
ACTD	Advanced Concepts Technical Demonstration
AD	Air Defense
ADS	Advanced Distributed Simulation
AFB	Air Force Base
AG	Application Gateway
AIM	Air Intercept Missile
AIRNET	Air Network
AIS	Aircraft Instrumentation Subsystem
AISI	Aircraft Instrumentation Subsystem Internal
AIU	Advanced Interface Unit
ARPA	Advanced Research Projects Agency
ATU	Advanced Translator Unit
AVTB	Aviation Test Bed
BATT	Basic Air Tactics Trainer
BBN	Bolt, Beranek and Newman
BBS	Brigade/Battalion Battle Simulation
BDA	Battle Damage Assessment
BFTT	Battle Force Tactical Trainer
BLUFOR	Blue Forces
BODAS	Brigade Operations Display and AAR System
BRT	Bandwith-Demand Reduction Techniques
BTF	Battalion Task Force
CAP	Corrective Action Point
CCS	Control and Computation Subsystem
CGF	Computer-Generated Forces
CMS	Communications security Material Systems
CMT	Critical Mobile Targets
CMTC	Combat Maneuver Training Center
CMTC-IS	Combat Maneuver Training Center - Instrumentation System
CN	Concentrator Node
CNA	Center for Naval Analysis
CONUS	Continental United States
CPU	Central Processing Unit
CRT	Cathode-Ray Tube
CS	Combat Support
CSS	Combat Service Support
CU	Comprehensive Union
DFAD	Digital Feature Analysis Data
DI	Dismounted Infantry
DIS	Distributed Interactive Simulation

DIU	DIS Interface Unit
DLogger	Data Logger
DMA	Defense Mapping Agency
DSI	Defense Simulation Internet (DIS + encrypted data)
DSN	Defense Switched Network
DTED	Digital Terrain Elevation Data
ENMC	Exercise Network Management Center
ES	Entity State
ESPDU	Entity State Protocol Data Unit
EW	Electronic Warfare
F-16	Falcon Star
FCTCLANT	Fleet Combat Training Center Atlantic
ftp	File Transfer Protocol
FTS	Federal Telephone System
FV	Functional Validation
GIS	Geographic Information System
GOI	Grids of Interest
GPS	Global Positioning System
GUI	Graphical User Interface
HDDS	HyDy Display and Debriefing Subsystem
HF	High Frequency
HOTAS	Hands on Throttle and Stick
HPTD	High Performance Tape Drive
HVUCAP	High Value Unit Combat Air Patrol
HyDy	Highly Dynamic
ID	Identification Number
IDA	Institute for Defense Analysis
IFOR	Intelligent Forces
INES	Improved Performance Network Encryption System (Motorola)
IP	Internet Protocol
ITD	Interim Terrain Data
iTIN	integrated Triangular Irregular Networks
LADS	Loral Advanced Distributed Simulation
LAN	Local Area Network
LN	Link Node
LOS	Line of Sight
LU	Local Union
Mbps	Megabits per second
MCAS	Marine Corps Air Station
MCC	Management Command and Control console
MFS	Manned Flight Simulator
MILES	Multiple Integrated Laser Engagement System II
MOA	Memorandum of Agreement
MoDSAF	Modulated Semi-Automated Forces
MTBF	Mean Time Between Failure
MUTTS	Multi-Unit Tactical Training System
NAWC-AD	Naval Air Weapons Center - Aircraft Division
NCCOSC	Naval Command, Control and Ocean Surveillance Center

NCS	Net Control Station
NOC	Network Operations Center
NOFORN	No Foreign
NRaD	NCCOSC RDT&E Division
NSA	National Security Agency
NSC	National Simulation Center, Ft. Leavenworth, KS
NTC	Naval Training Center
NTCS-A	Naval Tactical Command System - Afloat
NUWC	Naval Underwater Warfare Center
OPFOR	Opposing Forces
PDU	Protocol Data Unit
PICA	Protocol Independent Compression Algorithm
POC	Point of Contact
POP	Persistent Object Protocol
pps	packets per second
PVD	Plan View Display
QED	Quiescent Entity Determination
RAF	Royal Air Force
ROI	Regions of Interest
SAF	Semi-Automated Forces (simulator)
SAFOR	Semi-Automated Forces
SAM	Surface-to-Air Missile
SAWE	Simulated Area Weapons Effects
SE	Summary Entity
SE	Synthetic Environment
SEAF	STOW-E Evaluation and Analysis Facility
SEI	Systems Engineering and Integration
SGI	Silicon Graphics, Incorporated
SIMNET	Simulation Network
SIT	System Integration Test
SLF	Standard Linear Format
Soar	Artificial intelligence project charged with developing real-time aggressor simulation
SOI	Sphere of Influence
SOP	Standard Operating Procedure
SP	Stream Protocol
SSIT	Subsystem Integration Test
STOW-E	Synthetic Theater of War - Europe
TACCSF	Theater Air Command and Control Simulaton Facility
TACTRAGRULANT	Tactical Training Group Atlantic
TACTS	Tactical Air crew Combat Training System
TAF	Training Analysis Feedback Facility
TDB	Terrain Database
TEC	Topographic Engineering Center
TIN	Triangular Irregular Network
TIS	Tracking Instrumentation Subsystem
TOC	Tactical Operation Center
TR	Trouble Report

UCF	University of Central Florida
UHF	Ultrahigh Frequency
UO	Uninstantiated Object
USAF	United States Air Force
USAREUR	United States Army, Europe
VHF	Very High Frequency
VME	Versa Modula Europa (bus architecture for card cages in AIU)
VTC	Video Teleconferencing
WAN	Wide Area Network
WISSARD	What If Simulation Systems for Research and Development
WPC	Warrior Preparation Center

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13. ABSTRACT *(Maximum 200 words)*

This report details a joint research effort, the Synthetic Theater of War - Europe (STOW-E), that was run concurrently with ATLANTIC RESOLVE 94, a joint service training exercise. Many technologies and techniques were researched and implemented to enable live, virtual, and constructive simulation systems to be implemented into a seamless warfighting environment that will aid future warfighters in training and that will hone the skills required in a tactical environment.

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